# A socio-technical method to assess the holistic impact of new buildings on English secondary schools from the perspective of the students


| | |
|---|---|
| PRODUCED BY: | JOSEPH WILLIAMS |
| PRIMARY SUPERVISOR: | PROF DEJAN MUMOVIC |
| SECONDARY SUPERVISOR: | DR KERSTIN SAILER |
| INDUSTRIAL SUPERVISOR: | IAN TAYLOR |
| PRODUCED ON: | 14 JANUARY 2017 |

The Bartlett School of Environment, Energy & Resources

EngD Virtual Environment Imaging & Visualisation (VEIV) Centre for Doctoral Training

**This thesis is submitted in partial fulfilment of the requirements for the degree of Doctor of Engineering (EngD) at University College London**

**I, Joseph Williams, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated.**

## Abstract

Schools within England form a key part of society, educating future generations and providing continuity of lessons between generations. Recent UK governments have recognised their place within society and attempt to improve them through large building improvement programmes, most notably the recent Building Schools for Future (BSF) programme that aimed to replace or renew every secondary school in England. This focus on the building shows the political importance placed on the physical environment within education, but it is important to determine how the building influences the performance of schools. Previous research into the links between the physical environment and the school have tended to focused on individual aspects of the environment, with exceptions such as Barrett (2013), but to truly understand the influence of the building, the school must be analysed as a whole, capturing the interplay between the various aspects of the environment and school.

Capturing a total view of schools, this work established and implemented a holistic socio-technical approach to analysing the school. This approach consisted of two major strands; a national-level analysis of the performance of secondary schools that have received new buildings, and a school-level analysis that evaluated the measured and perceived environment of four case study schools. This national-level study necessitated the construction of a large, longitudinal database, merging the school data with the building data, covering a period of 13 years. Within the school-level analysis four main techniques were applied; environmental measurements, spaces syntax analysis of the built form, a bespoke student questionnaire, and an immersive virtual feedback tool (the Interactive Space Analysis Tool, ISAT) developed as part of this research. These four tools were co-analysed using multi-level modelling, enabling comparisons between the results of the different tools.

The combination of the national and school level analysis allowed the holistic impact of new school buildings to be analysed. The national level analysis revealed the performance of schools in their new BSF buildings, school attainment improving prior to the move into the new building, but returning to the initial level after four years of occupation. At a school level, the mixed-methods utilised found that the measured internal conditions met the criteria set by the design guidance, with the students noting that the look and feel of the school was the most important aspect of the building. Co-analysing both the national and school level results shows that the school and the building need to operate as one unit to achieve the best results once the initial novelty of the new building declines. Building on the findings, the importance of treating the school as a whole is discussed, with the implications on the school building design noted, as well as suggestions for future holistic studies into the school environment.

The following publications were produced during this research

## Journal Papers

Williams, J. J., Hong, S. M., Mumovic, D., Taylor, I. 2015. ‘Using a unified school database to understand the effect of new school building on school performance in England’. *Intelligent Buildings International*, 7 (2-3): pp. 83-100.

Williams, J. J., Mumovic, D., Taylor, I. 2017 (expected). ‘A comparative study of the influence of the school building on student performance’. *Building and Environment.*

## Conference Papers

Williams, J., Sailer, K., Priest, R. 2015. ‘Use of an online interactive space analysis tool to understand student perceptions of four secondary schools’. *10th International Space Syntax Symposium (SSS10)*, 13-17 July 2015, University College London, London, Paper 038.

Williams, J. J., Hong, S. M., Mumovic, D., Taylor, I. 2013. ‘Assessing the social aspects of energy use in school using a unified database’. *CIBSE Technical Symposium*, 11-12 April 2013, John Moores University, Liverpool, Session 11, Paper 4.

## Book Chapters

Williams, Joe Jack. 2015. ‘The Environment of Schools’. In: Clegg, P, *Learning from Schools*. London. Artifice Books on Architecture.

Williams, Joe Jack, Taylor, I. 2015. ‘Energy Use’. In: In: Clegg, P, *Learning from Schools*. London. Artifice Books on Architecture.

## Contributing Author

CIBSE. (2015). *CIBSE TM57: Integrated School Design*. Guide. London: The Chartered Institution of Building Services Engineers.

## Acknowledgements

This research was jointly funded by the Engineering and Physical Sciences Research Council (EPSRC), through the UCL Virtual Environments, Imaging and Visualisation doctoral training centre, and by Feilden Clegg Bradley Studios architectural practice, through their UCL-FCBS Educational Building Design and Performance Research programme.

Firstly, I must extend my thanks to my primary supervisor, Professor Dejan Mumovic, for his tolerance, guidance, and for enabling this whole process from the very beginning. I am also grateful to my secondary supervisor, Dr Kerstin Sailer, for her continued support and keen eye for detail. At the very beginning of this research, I was also fortunate to be given guidance by the late Harry Bruhns, for which I am indebted, and who's legacy within UCL continues to this day. A special mention must be extended to Lia Chatzidiakou who assisted with the site monitoring at each school and put up with my driving. In addition, I would like to thank the other doctoral researchers at UCL, who have provided support and shared their knowledge from the start.

This research would not have been possible had it not be for the support of Ian Taylor at Feilden Clegg Bradley. His insight into schools and their design has been instrumental into my research approach, for which I am incredibly appreciative. Richard Priest deserves a special mention for his is assistance with programming throughout the EngD process. Without the support of everyone at Feilden Clegg Bradley, this work would not have been possible, their energy and drive has kept me going throughout, as has their willingness to answer my many questions, and I cannot thank them enough.

None of this research would have been possible without the support of my family, particularly my parents, who instilled the necessary curiosity in me at a very early age and continue to nurture it to this day.

A special thanks is extended to my partner, Beth. Throughout my research, she has been a continuous source of stability, and without her support I have no doubt that this would not have been possible.

## CONTENTS

## Figures

## Tables

# 1 Introduction

Education is often thought of as the corner stone of society, passing on the learnings from previous generations to the next, creating a cycle of continuous improvement. Within England, as with many other countries, a formal education system is in place that aims to provide a universal foundation of skills necessary to produce citizens that contribute to society (OECD, n.d.-a). Analysis by the Organisation for Economic Co-operation and Development (OECD) (Hanushek, Woessmann, Jamison, & Jamison, 2008; Hanushek & Woessmann, 2007) showed that there is a direct and measurable link between improving education and an increase in the Gross Domestic Product (GDP) of the country. With this strong link, it is no surprise that there are international schemes comparing the performance of education in different countries, notably the Programme for International Student Assessment (PISA), the Trends in International Mathematics and Science Study and the Progress in International Reading Literacy Study (TIMSS and PIRLS). The strong links between education and economics, as well as the simple international comparisons these programmes enable, make education a political battleground, with education policies regularly featuring in party political manifestos (Mahony & Hextall, 2013).

To enable a nationwide education system, a considerable amount of infrastructure is required, with circa 24,000 school buildings provided in England (DfE, n.d.-a) to educate every child until they reach adulthood. Given the recent economic crash of 2008, any spending by the English government is subject to considerable scrutiny, including maintaining and expanding the school building stock. The government at the time of the economic crash had implemented an ambitious programme of replacing or renewing every secondary school in England; the Building Schools for Future programme (BSF). This programme aimed to improve a total of 3,500 schools at a cost of up to £55 billion that would take until 2023 to complete (Mahony & Hextall, 2009). However, this programme was cancelled following a change in government in 2010 and a review ordered into the spending. The James Review was commissioned by the British government in 2010 (James, 2011) and examined the previous government's BSF programme. Among other findings, the review found that the BSF programme had high costs with the ability to make 30% savings, and that any future school building programmes should focus on the schools in greatest need of a new building, leading to the development of the current Priority School Building Programme (PSBP).

Examining school buildings as capital expenditure projects without considering the wider impact negates the initial political impetus that created the school building programmes; namely to improve education. However, despite the links between education and the national economy, there is little consensus on the influence of the built environment on the school themselves. The literature review by Higgins et al. (2005) examined the research into the built environment of schools, finding that in general the overall state of educational environment research contained many gaps or areas that needed further clarification. A key theme of a majority of research into the built environment within schools is the focus on a singular aspect of the environment, exploring the direct influence that the aspect has on educational performance (predominantly a form of exam score). While this approach is able to find strong links between the environment and school performance, for example the work on noise by Shield et al. (2004), this work often overlooks the complexity of a school, with the interplay of the occupants and the many aspects of their environment regularly controlled rather than explored. While work by Barrett et al. (2013) took a holistic approach to evaluating the influence of the built environment, the human element of the school remains implied rather than explicitly measured.

This study will quantify the links between the occupant and their built environment, enabling the impact of the environment to be explored from the point of view of the students. This focus on the students necessitates a holistic methodology, capturing the whole of the school including the built environment. Whereas previous investigations into the school built environment have focused on individual aspects of the environment, within this body of work it will start with the occupants and the school performance. By framing the issue of school building design from the perspectives of the students, it will be possible to determine what they focus on within their environment and then compare it to the measured environment. These aspects of the school that they focus on will necessarily have a degree of importance to them and as such their experience of the school, with potential consequential influence over their academic performance (whether performance in tests, absenteeism, or social interaction metrics).

Throughout this research, the interplay of the school and their environment will be examined. To assist with clarity of discussion, the school as an operational entity will be referred to as the *school climate*, and the building as the environment (encompassing all aspects of the built environment). The school climate will for example include procedural aspects such as; teaching, student management, student/teacher connectedness, and management structure, whereas the environment will include physical aspects such as; air quality, circulation routes, visibility, temperature, and floor area. Practically, there is overlap between the environment and the school climate, something which will be explored within this work.

## 1.1 Research Aims, Questions and Objectives

With the complex environment of a secondary school, it is particularly difficult to grasp the relative impact of the various aspects of the school climate and built environment on the ultimate output of the school, predominantly the education of the students. As such, this body of work will take a highly exploratory approach, using mixed-methods to establish the impact of the new school environment on the educational outputs, underpinning this with an examination of the perceived and measured environment in four recently constructed school buildings. This multi-method approach will then be able to inform the future of school building design as well as pave the way for future multi-method studies into school buildings.

With the highly exploratory nature of this research, there are four important questions to be addressed by this research

1. How do student perceptions of the built environment interact with the measured school environment?
2. What is the impact of a new building on the academic school performance (exams and absenteeism)?
3. What are the most important aspects of the built environment to the students within their school?
4. What are the implications on future school research and design arising from the exploratory methods used within this study?

In order to answer these questions, a number of specific objectives need to be met:

- Development of a longitudinal unified school database, matching school and building data
- Analysis of school performance before and after receiving a new school building
- Determination and quantification of the built environment of the case study schools

- Quantification of the student perception of their school built environment using a new, bespoke feedback tool
- Co-analysis of the case study school data using multi-level modelling to determine links between perceived environment and the measure environment

## 1.2 Structure of the Thesis

With over 3,500 secondary schools in England, a detailed, sample based-study into the schools and their environment would require a sample of at least 347 schools to be significantly significant[1], which is too large for an exploratory study of this nature. Instead, a two-part approach to the research has been created, firstly looking at national trends in secondary schools, followed by an in-depth analysis of four secondary schools. The national-level analysis will provide overall trends in school performance, but will not explain the actual processes happening that create any observable changes. The school-level study will develop a holistic Post-Occupancy Evaluation methodology (POE) that will examine both the perceived and actual school environment to illuminate the link between the built environment and the school that may account for any national trends.

To capture this two-tier research methodology, the thesis follows a correspondingly split format as shown in Figure 1.1. The methodologies and corresponding results are split into national-level and school-level, each starting with an overview of the case studies used within the sections. Within the school-level research, the methodology and results are further split into three distinct sections, each using the same case study schools, but representing the particular approaches taken with the school-level analysis.

[1] Based on 95% confidence level, 5% confidence interval.

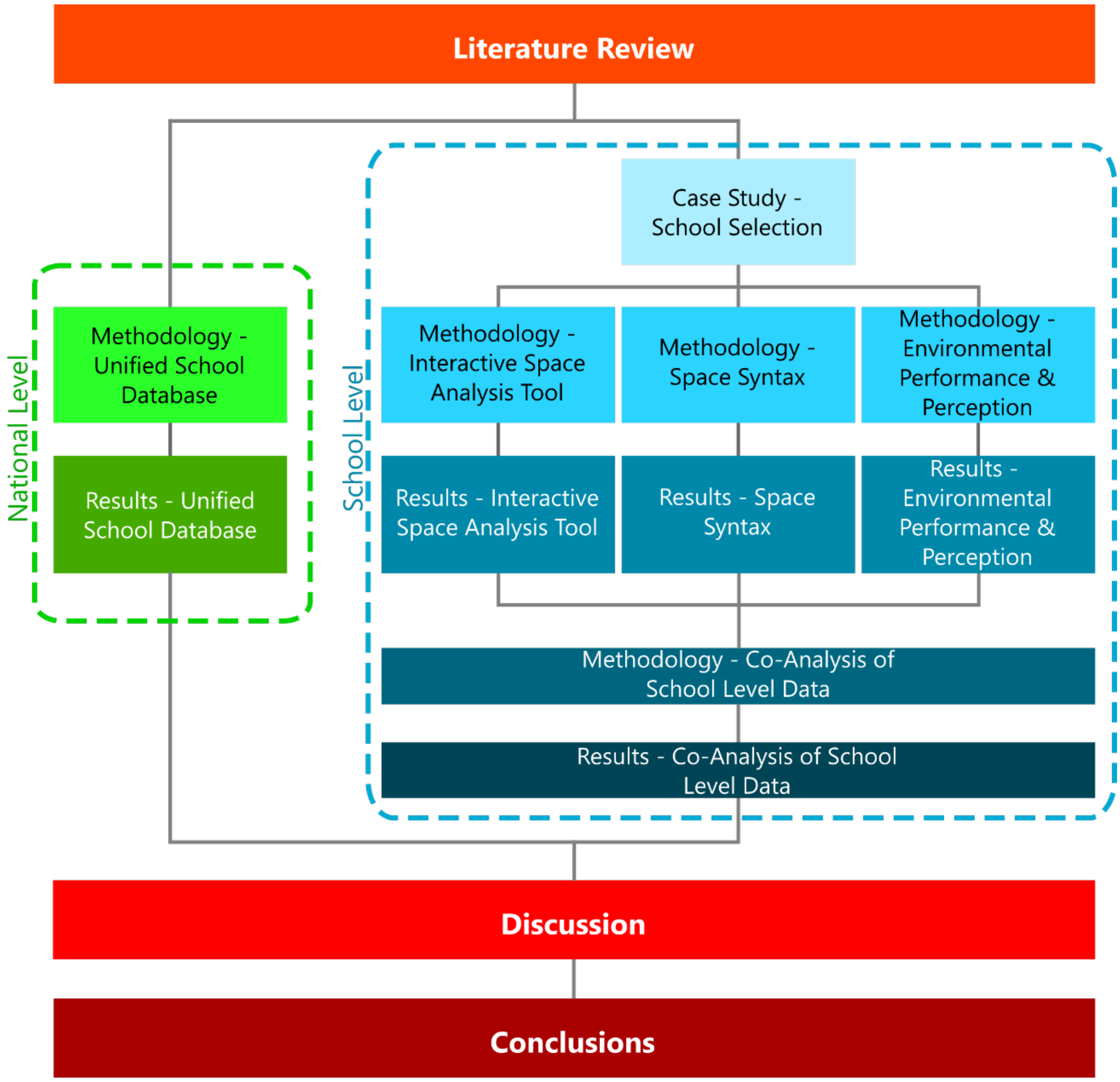



**Figure 1.1 – Structure of thesis, showing the relationship between the national level section and the school level sections**

The thesis is structured as follows:

- **Chapter 2, Literature Review**

  The literature review is split into two predominant sections, reflecting the two levels used with this research; national and school level, with an additional section evaluating other holistic studies into the school environment. Within the national level section, a general background to the school system in England is given, covering the structure of education and the typologies of the school buildings themselves. A review of the methods of measuring academic performance is covered, discussing the relative merits and limitations of attainment and absenteeism as an indicator of overall school performance.

Within the school level background section, the impact of the school building on the school performance are examined, including the indoor air quality, thermal environment, access to light, acoustic environment and the built form itself. In addition to the influence of the building, this section also contains research into the methods of measuring the total performance of schools; space syntax to measure the built form, occupant feedback and the frameworks for measuring the school climate. It will also look at previous studies that have attempted to measure the holistic performance of the schools and their buildings.

- **Chapter 3, Methodology: Development and Analysis of the Unified School Database**

  In order to understand the general trends of the schools that received new buildings under the Building Schools for Future (BSF) programme a large database covering every secondary school in England has been constructed. This section details the construction and analysis of this large unified database. The methodology of matching the various datasets both within years and across years is outlined, including the school datasets from the Department for Education (DfE) and the Display Energy Certificate (DEC) datasets. Using the unified school database, the separate analyses are outlined; energy performance of new school buildings, influence of the changing school environment, performance of the school before and after the new building, and effect of the internal environment on school performance.

- **Chapter 4, Results: Development and Analysis of the Unified School Database**

  Using the unified school database, this chapter outlines the results of analysing new secondary schools at a national level. Firstly, the energy performance of the buildings built under the Building Schools for Future (BSF) programme are compared to the existing schools, with a complimentary analysis exploring links between school academic performance, deprivation and energy performance. Following the examination of the energy performance, the academic performance of the BSF schools is examined, looking at the process of building a school and any influence of the built environment.

- **Chapter 5, Selection of Case Study Schools for School Level Analysis**

  In parallel with the national-level study of secondary schools within England, this research examines four recently built schools, applying a multi-method, socio-technical approach to include all aspects of the school This chapter introduces the criteria the four schools have been selected against, as well as providing key background information prior to the analysis.

- **Chapter 6, Methodology: Interactive Space Analysis Tool**

  Complementing the guided feedback from the students (from the questionnaire), this chapter outlines the development and application of a new feedback tool that collects unguided feedback, the *Interactive Space Analysis Tool* (ISAT). The ISAT is accessed through a web browser and presents the students with a virtual navigable version of their school building, enabling them to comment on visual aspects as well as any other aspects that are important to them. This chapter also describes the use of *grounded theory* to analyse the results from the students at each school and the use of multi-level modelling to compare the findings with the measured/perceived environmental performance to understand the characteristics of the new tool.

- **Chapter 7, Results: Interactive Space Analysis Tool**

  This chapter gives the results of the ISAT within each school, first examining the characteristics of the return rate, then presenting the results of the grounded theory to categorise the comments made by the students. Using the occurrence rate for each of the properties established under the grounded theory, the perceptions of the students are explored, with the comments used to compare opinions on each school.

- **Chapter 8, Methodology: Social Aspects of Space - Space Syntax**

  Space syntax provides a toolset to quantify the building layout, using network theory to examine the connections between the visibility of the space and the type of movement expected. Within this section, the Visual Graph Analysis (VGA) applied to the four case study schools is described, along with the specific metrics of *integration*, *intelligibility*, *mean depth.*

- **Chapter 9, Results: Social Aspects of Space - Space Syntax**

  Using the space syntax tools, the building layouts of the four case study schools are analysed and the results are presented within this chapter. Using each metric from the VGA (integration, intelligibility and mean depth) the case study schools are compared to each other, identifying common traits and expected modes of movement from previous literature.

- **Chapter 10, Methodology: Environmental Performance and Perception**

  At the school-level, this chapter outlines the methodology for measuring the perceived and actual environmental performance of the four case study schools. The aspects of the internal environment that were measured are outlined along with the specific methodology for each environmental aspect. A question is also developed within this chapter to measure the perceptions of the students on their built environment and their wider attitudes towards the school.

- **Chapter 11, Results: Environmental Performance and Perception**

  Within chapter 11 the results of the environmental performance and perception at each of the four case study schools is presented. The environmental data is summarised, showing the averages for each school during the occupied hours of the monitored period. In addition, summaries of the student questionnaire are presented, giving an overview of the students' perception of their school and building. This is complemented through using factor analysis to expose the underlying themes within the questionnaire data.

- **Chapter 12, Method: Co-Analysis of School Level Data**

  At the school-level, the multiple methods of analysing the school have been comparatively separate, however this chapter introduces the statistical modelling that enables robust comparisons between the perceived environment and the measured environment. This is undertaken using *multi-level modelling*, which captures the tiered nature of the data while handling the different types of data created through this work (both discrete and continuous). Three statistical models are created, comparing the environmental data (including space syntax), questionnaire data, and ISAT results in pairs. In addition, the method of analysing the movement within the ISAT and the space syntax are introduced.

- **Chapter 13, Results: Co-Analysis of School Level Data**

  This chapter presents the results of the co-analysis of the school level data described in chapter 12. The ISAT navigation analysis is presented first, followed by the multi-level modelling. The multi-level modelling is broken down into three sections, firstly comparing the environmental data with questionnaire data, followed by modelling the ISAT results with the questionnaire data, and finally comparing the ISAT results with the environmental data. Using these results, the underlying connections between the student perception and the measured environment will be exposed. In addition, the relative performance of the questionnaire and the ISAT will be compared, with the specific characteristics of each exposed.

- **Chapter 14, Discussion**

  Within the discussion, the two main streams of this research, the national and the school level, are examined in conjunction to provide an overall view of the effect of the built environment on schools. In addition, the relative success of the mixed methods used within the school-level analysis will be discussed, with a particular focus on the impact the Interactive Space Analysis Tool within the holistic methodology. Using the findings from this research, the implications on future school building design will be expressed.

- **Chapter 15, Conclusions**

  In concluding this work, this chapter will evaluate firstly the progress against the stated aims, objectives and research questions. It will also discuss the wider value of this work, notably the contribution to knowledge, limitations within the research and make recommendations for future research that could extend this work.

# 2 Literature Review

Education as a concept covers many different forms, from handed-down lessons to formal, government-backed curricula. Even within formal education systems, there can be substantial differences between teaching pedagogy, reflecting not only the culture that created the teaching system, but also the socio-economic situation of the country/area. Intrinsically, any research on education will be location specific, although trends can be drawn from other education systems. This body of work will focus on the English education system, with a long history and a corresponding breadth of applicable research. With the focus of this work on the built environment, the English education system represents an opportunity to explore the impact of the recent spate of new buildings, the largest of its type at the time.

The literature review is split into three sections, reflecting the key themes within this work; schools at a national-level, the influence of the built environment, and integrated case studies.

## 2.1 National Level: Schools in England

Education in England is dominated by state-funded schools, which receive funding and guidance through the relevant department (currently the Department for Education, DfE). However, there are also privately funded schools that operate in tandem with the state-backed education system, which can operate to entirely different pedagogical ideals, such as the Waldorf-Steiner pedagogy. One of the key principles of this research is to ensure relevance to a majority of schools in England, and as such alternative school provisions will not be examined. It should also be noted that school systems in England are not necessarily the same as those in Scotland, Wales or Northern Ireland, although their roots are similar, local influences drive change in the structure of education and comparisons need careful consideration (Raffe, 2004).

### 2.1.1 Educational System in England

State-funded schools (maintained schools) are either directly or indirectly funded by central government through the DfE, which stipulates minimum requirements for the quality of education provided, and are overseen by the regulatory authority Ofsted (the Office for Standards in Education, Children's Services and Skills). Within this section, the education system set by the DfE will be discussed, based on the national curriculum[2] (DfE, 2014).

Every child in England is required to be in full-time education from 5 years old until they are 16, after which they have the opportunity to continue up to 18 years old. The school system is broken down into five main key stages that correspond to the stage within the national curriculum, set by the DfE (source (DfE, 2014)):

- Key Stage 1 (*KS1*), year 1 and year 2, corresponding to ages 5 to 7
- Key Stage 2 (*KS2*), year 3 to year 6, corresponding to ages 7 to 11
- Key Stage 3 (*KS3*), year 7 to year 9, corresponding to ages 11 to 14
- Key Stage 4 (*KS4*), year 10 and year 11, corresponding to ages 14 to 16
- Key Stage 5 (*KS5*), year 12 and year 13, corresponding to ages 16 to 18.

During each stage, the DfE has an agreed national curriculum that covers the subjects to be taught and expected progress, measured through tests during the final year. These subjects include an element of choice as the pupil progresses through the key stages, with an acceptable level of variation within subject areas (humanities or language being common areas for variation).

The school system within the England generally unites KS1 and KS2 in the same school, a primary school, and KS3 and KS4 within a secondary school. There are more primary schools in England than secondary schools (DfE, n.d.-a), with primary schools serving smaller local communities and secondary schools acting as hubs. Additionally, in some parts of England, there is another set of schools, known as middle schools, which operate between secondary and primary schools, with varying age ranges, but typically falling into two categories: *middle-deemed-primary*, accepting pupils up to age 12 (year 7) and *middle-deemed-secondary*, accepting pupils over age 13 (year 8 and above)

Due to the structure of the key stages, it is increasingly rare for the middle schools to continue, with the overlap of key stages between schools creating a lack of continuity during each stage. In addition, each school is treated as either a primary or secondary school in the reporting to central government, increasing complexity of monitoring and reporting at a national level.

---

[2] Note that while the general structure of the national curriculum is unlikely to change substantially year to year, the particulars can and do change with time, notably with changing governments.

Following on from KS4 is the optional stage, KS5, taught at 6th form centres attached to secondary school or at dedicated colleges. During this stage, the courses are selected by the student, with the aim of preparing for higher education.

### 2.1.2 Alternative School Types

In addition to the maintained and independent schools, a number of Special Education Needs (SEN) facilities also exist, providing services to children with identified disabilities that necessitate specialist teaching. These SEN facilities can also provide an element of therapy, such as light therapy, and act to develop the pupils in other ways than through the national curriculum.

As part of the English school system, an additional type of school was introduced in 2000; city academies (later just academies) (Hatcher & Jones, 2006). In Hatcher and Jones' discussion on the academies, they cover the history of the academies and reason behind their creation, establishing that they are designed to operate independently from the local authority, and initially required a sponsor to assist with the academy. They note that the first academies were aiming to improve those schools identified as under-achieving, utilising the skills and funding from business to assist, known as 'sponsored academies'. The academy programme was extended to include 'converter academies', where all schools were eligible to change into an academy without the need for a sponsor, instead operating under a charitable trust.

Both of these academy types are funded centrally through the Education Funding Agency (EFA), part of the DfE, whereas 'standard' schools receive funding through the local education authority. The separation of academies from the local authorities extends to the management of the school, with academies allowed to approach education in a flexible manner, embracing new teaching pedagogies, while still meeting the requirements of the national curriculum. Many academies extend this flexibility to focus on a particular aspect of education, business or ICT for instance, with many schools benefiting from sponsorship by a company or trust and the experience they can bring. Despite the different funding and control of the academies, a number of them received new buildings under the government school building programme, converting to the academy programme following the occupation of the new building. Additionally, many academies received a new building under the original sponsored academy programme, with additional funding from the sponsor making the new building possible.

### 2.1.3 Overview of School Building Design

The construction of new school buildings in England falls into three predominant phases; late 19th century to early 20th century, the 1950s to the 1970s, and the BSF programme of the mid-2000s (Clegg, 2015, Chapter 1). The driver for each of these building phases is different, with each responding to a particular need at that point in time. Few schools were built outside of these phases, largely caused by the large financial investment of building a new school (Clegg, 2015). Summarising the work of Hawkes (in Clegg 2015) and Harwood, the history of school design within England has been explored.

#### *The first phase: 1870-1918*

The first phase of school building in England began with the publication of the 1870 Elementary Education Act, designed to ensure there was sufficient education provision in each of the local authorities in England (DfE, n.d.-c). Prior to this, education was largely only available to those who could afford to pay for an education, but the 1870 act opened up education to a much wider audience. This need for education was further cemented by the 1876 Royal Commission on the Factory Acts that prevented child labour, and finally made education compulsory in 1880 (DfE, n.d.-c). Given the shift within 10 years, England needed a considerable number of new buildings to provide the now compulsory education.

Within London, E.R. Robson was appointed as the Chief Architect of the London School Board and published a design guide in 1874 that effectively became the design guide for the new wave of schools (Robson, 1972). The schools that sprang up after the publication tend to be very similar, with classrooms either side of a central hall, removing the need for corridors as shown in Figure 2.1. Typically the schools were three stories tall, with each floor representing a sub-division of a school, by age and/or gender (Steadman, 2014). The classrooms themselves had large windows (owing to the rarity of artificial light at the time), and towards the end of the 19th century there was focus on ventilation as a way to prevent disease, with some schools trialling early versions of mechanical ventilation (Steadman, 2014, p. 145). In a reform of the Education Act in 1902, schools were more formally split into primary and secondary schools, enabling them to compete with the existing private, grammar schools of the time.

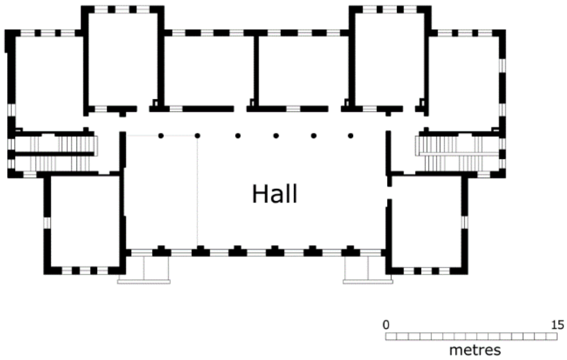



**Figure 2.1 – Layout plan of the Jonson Street School, Hackney, with the central hall (right © Feilden Clegg Bradley Studios)**

The end of the First World War effectively saw the end of large scale school construction within England, caused by the significant economic difficulties the country faced. Although significantly fewer schools were constructed, during this period the environment of the school was beginning to be recognised as important, with the ventilation and daylight levels receiving particular attention (Franklin, 2009).

### *Post-war baby boom era: 1950's and 1960's*

Following a period of few schools being constructed between the wars, the post-war period saw a population boom that necessitated the construction of many new schools. Between 1950 and 1960, the secondary school population increased over one million, the so called 'baby boomers', as shown in Figure 2.2.

Given the rapid expansion in the population, new schools had to be created at a high rate and this naturally led to pre-fabricated building systems, notably the CLASP system (Harwood, 2012). This CLASP system used a pin-jointed steel frame with a simple cladding to quickly create buildings that could be readily configured to meet the specific site requirements (see Figure 2.3 for a typical school of the period). This period also saw the launch of Building Bulletin 2 that set out the overall guidelines for the new schools, incorporating formalised concepts of daylighting and natural ventilation (Clegg, 2015). With the tight financial costs and the often tight sites, the schools moved towards stacks of identical classrooms joined by corridors, often with a large hall in a separate block (Clegg, 2015).

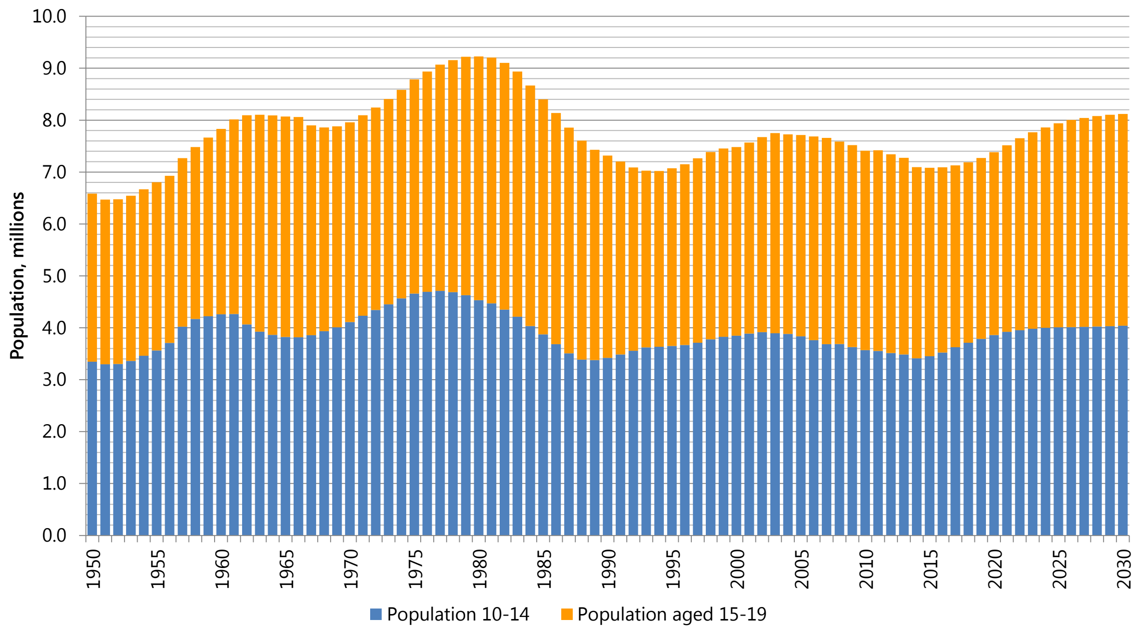



**Figure 2.2 – Bar chart illustrating the population of students between 10 and 19 since 1950, representing the number of students requiring a secondary school place (data source OECD (n.d.-b)).**

With the initial sharp rise in the school population over by the late 1970s, the population within the secondary school dropped, with the echoes of the initial baby boomers creating the generational changes in school population seen in Figure 2.2, underpinned by a general upward trend in population. However, the new schools built to educate the post-war children were able to effectively accommodate the English secondary school population in terms of raw space required, considerably reducing the demand of new school buildings after this initial construction boom.

### *The new wave: 2000's and the BSF Scheme*

The development of the Building Schools for Future (BSF) programme was long and complex, with many smaller fore-running programmes, as uncovered by the House of Commons Education and Skills committee during their investigation into the BSF programme (Education and Skills Committee, 2007). Initially the BSF programme started as a smaller programme in 1998 with the aim of tackling the backlog of maintenance in English secondary schools, while encouraging updates to the infrastructure to enable modern learning (Education and Skills Committee 2007, para. 9). This then developed into a scheme named the New Deal for Schools, with the focus moving towards improving the school performance through enhancing the facilities provided, through reducing class sizes and curtailing the dependence on temporary classrooms (Education and Skills Committee 2007, para. 12). Taking the concepts of the previous school funding initiatives, the government then formally created the BSF programme in 2004, with the aim of providing a minimum standard for secondary schools and improving the teaching and learning capabilities (DfES, 2004). This scheme was developed to improve all secondary schools in England, as such the scheme prioritised schools with the "*greatest educational and social need*" (Education and Skills Committee 2007, para. 26), with a number of "waves" dictating the pace and scope of the programme. Unlike the previous large scale school building programme of the 1950s, the BSF programme was focused on the need to improve the building stock, not just create space to be used for teaching due to increasing population. This was a fundamental shift in the ethos of school building, echoing the design shift seen in the interwar years.

**Figure 2.3 – St. Crispin's Secondary Schools, Wokingham, © Architectural Association Photo Library.**

The schools themselves were well funded and suggested as new pillars of the community (Kraftl, 2012), leading to high profile architects such as Zaha Hadid[3] and Norman Foster[4] among others to design new schools. In order to justify the greater costs, the programme was initially intended to be largely funded by the Private Finance Initiative (PFI), where the school is leased back from the contractors over a fixed period (typically 25-30 years) while they operate and maintain the building as part of a fixed annual fee. Part of the brief for the BSF programme was to provide

3 Evelyn Grace Academy: http://www.zaha-hadid.com/architecture/evelyn-grace-academy/ (last accessed 18/02/2016)
4 Corby Business Academy: http://www.fosterandpartners.com/projects/corby-academy/ (last accessed 18/02/2016)

flexible teaching and transformative learning (Education and Skills Committee, 2007). This flexibility combined with the large budgets led to the development of new layout typologies, such as open plan teaching spaces (although this in itself was not a new principle with schools in the early 19$^{th}$ century trialling this configuration (Steadman, 2014, p. 132)). In addition to the increased flexibility of the layout, the schools were also to ensure that the internal environmental conditions were closely controlled to produce the optimal learning environment. Given the lack of schools recently built prior to the start of the BSF programme, there was a collective paucity of school construction experience within the industry (Higgins, Hall, Wall, Woolner, & McCaughey, 2005), leading to the industry to turning to the building bulletin guides as briefs for their buildings (Education and Skills Committee, 2007). The 33 building bulletins (as of 2008) covered all aspects of the built environment and represented the best of the contemporary research in that subject area, but were never intended to be as stringently enforced as they became (forming part of the building brief).

With the change in government in May 2010, the BSF programme was officially closed soon after, with a majority of the proposed new buildings cancelled (over 700 were cancelled (Mahony & Hextall, 2013, p. 863)). The BSF programme was accused of being difficult and expensive to procure, with main contractor Skanska claiming a failed bid cost the company £5 million (Mahony, Hextall, & Richardson, 2011a, p. 348) and the James review (James, 2011) finding the programme unsuitable for the future of schools. Given the high cost of the procurement, a court case was launched by a collective of six councils against the decision to cancel BSF, aiming to claim back an estimated £230 million wasted by local authorities in procurement of new buildings under the BSF prior to the cancellation (Mahony & Hextall, 2013, p. 863). Despite winning the court case, no new schools were built by the councils. New schools continue to be built under new schemes, including the Priority School Building Programme, noting that in the next 15 years there is expected to be around 1 million more secondary school places needed (see Figure 2.2).

### 2.1.4 Measuring School Performance

In order to understand the relative success of schools and their buildings, it is first necessary to understand how their performance can be measured. Within the English school system, there are two predominant metrics for comparing schools; attainment and absenteeism. With the end of compulsory education in England[5] culminating in the GCSE exam, many secondary schools are judged on the overall school performance in these exams. There are a number of different bracketing methods utilised by the DfE to assist with their interpretation, but historically the most common are as follows:

- Level 1: Percentage of eligible students achieving 5 or more GCSEs at grade G or above
- Level 2: Percentage of eligible students achieving 5 or more GCSEs at grade C or above
- Level 2 including English and Maths: Percentage of eligible students achieving 5 or more GCSEs at Grade C or above including in English and Maths
- KS4 Progress: Percentage of eligible pupils making expected progress based on previous Standardised Attainment Tests (SATs) taken at end of KS3 in English or Maths

Attainment figures, such as those above, illustrate the purely academic performance of a school, reflecting the schools' ability to prepare the students for tests against the national curriculum. At an individual level, McEvoy & Welker (2000) showed that poor academic performance can also be an indicator of wider social problems with the students, notably anti-social behaviour, although this is difficult to determine at a school level. Similarly, absenteeism is used as a metric for comparison of schools, with four predominant types recorded: total, authorised, unauthorised, and persistent (defined as 38 or more half-days over two of the three terms DfE (2009)). Absenteeism can be thought of a proxy for engagement, particularly unauthorised and persistent absenteeism, with Kearney (2008) and Attwood & Croll (2006) showing the importance of the school in encouraging the students to attend. However, few school performance metrics are recorded year on year, with the DfE (and its predecessors) changing their policy regularly.

Attainment and absenteeism are widely seen as the outputs of schools, particularly in the media, but there is a growing case for measuring the social and behavioural impacts of the students within the school. The area of *student engagement* focuses on the importance of these behavioural matters and has been growing since it was first conceived in 1985 by Mosher and MacGowan (1985). However, given the complexity of schools, a paper by Appleton et al. (Appleton, Christenson, & Furlong, 2008) has found that there were eight different definitions in wide use,

---

5 While this is strictly true, recent changes by the current government require that all persons between 16 and 18 are to be in either education or work, considerably increasing the number who stay on for a further two years to complete A-level exams.

hampering its use in future work. Appleton concludes that the "... *most imperative and pressing direction for future research involves establishing construct validity for student engagement.*" (Appleton et al., 2008, p. 383). Given the difficulty in defining engagement as a framework it is not surprising that it is not widely used, however in the future it could provide an incredibly robust means for comparing school performance.

### 2.1.5 Assessing the Operational Performance of the School Building Stock

School buildings not only have an obligation to assist education, but also a wider need to reduce the global impact of the buildings through reducing unnecessary carbon emissions. Secondary schools alone were estimated to emit 4.4 million tonnes of carbon dioxide per annum in 2006 by the Global Action Plan (Global Action Plan, 2006), equating to 0.62% of the UK's total annual carbon dioxide emissions. While this is a small, but significant, percentage of the of the overall UK emissions, there is a strong argument that schools should be setting the example of energy efficiency, educating future generations on the principles of low-energy building operation, reducing carbon emissions within other areas of the UK.

The Chartered Institute of Building Service Engineers (CIBSE) published benchmark figures for energy use across many non-domestic buildings types including schools with their Technical Memorandum 46 CIBSE (2008). Their analysis found that a typical school (either a primary or a secondary) will use 40 kWh/m$^2$/annum of electricity and 150 kWh/m$^2$/annum of fossil-thermal energy (typically for heating and hot water), based on the gross internal floor area (GIFA). These figures underpin the Display Energy Certificate (DEC) programme within England (DCLG, 2008), where every public building over 1000 m$^2$ (later 500 m$^2$) is required to publicly display their energy use, along with a comparison against expected energy use based on the energy benchmarks provided by CIBSE and according to the methodology with CIBSE's Technical Memorandum 47 (CIBSE, 2009).

The work by Bruhns et al. on behalf of CIBSE (Bruhns, Jones, & Cohen, 2011) analysed 15,335 school buildings that acquired a DEC and found that the benchmark for schools are generally accurate, although secondary schools use more electricity than the benchmark, but also less fossil-thermal energy[6]. In a separate piece of work using the DEC data, Godoy-Shimzu et al. (2011) found that the mean electricity usage within secondary schools was 50 kWh/m$^2$/annum (higher than the CIBSE benchmark), and 138 kWh/m$^2$/annum for fossil-thermal fuels (lower than the CIBSE benchmark), aligning with the work of Bruhns et al. Additionally Godoy-Shimzu et al. found a strong relationship between climate and fossil-thermal energy use ($r = 0.65$), but little correlation between climate and electricity consumption ($r = 0.07$). Heating and ventilation systems were shown to significantly impact on the energy use, with mechanically ventilated buildings using more electricity, but less fossil-thermal energy than naturally ventilated buildings. Pupil density was also found to be a key factor in the overall building energy use (in the form of carbon emissions), with decreasing pupil density increasing the rate of carbon emissions per pupil, speculating that electrical equipment can be shared across greater numbers and the higher densities of students reduce the amount of heating required through additional heat gains. The influence of the built environment on school energy use was further explored by Hong et al. (Hong, Paterson, Mumovic, & Steadman, 2014), using artificial neural networks to identify the underlying patterns. Their work found that the electricity use was influenced by the number of pupils and the floor area, where as the fossil-thermal energy use was strongly linked to the ‘compactness’ of the building form and the construction year.

## 2.2 School-Level

Within the school itself, there are a number of actors that could influence the overall performance of the school. From the built environment to the relationship between the students and teachers, each could influence school. In order to understand the overall influence a new building can have on a school, it is important to explore the existing research into each aspect of the school.

### 2.2.1 Influence of the Student Background

Schools are there to help the student learn, but the influence of the environment outside the school will also have a direct impact on the student performance. While schools are widely compared using the attainment and absenteeism, the use of these without accounting for the student background has been shown to be misleading. Goldstein and Thomas (1996) and

[6] The comparison paper by Bruhns et al. focuses on Energy Usage Indices (EUI), where 100 is equivalent to the CIBSE TM46 benchmark. Within their paper, they found that the median electricity use was 115, and for fossil-thermal is was 82, with a median overall DEC rating of 98, close to those initial figures.

Goldstein and Spigelhalter (1996) discussed many of the underlying causes of perceived poor school attainment performance, noting that the variation in the background of the students was a significant factor in the diversity of school performances, and Attwood & Croll (2006) discussing this in terms of absenteeism. Using data from the TIMSS[7] study (TIMSS and PIRLS, n.d.), Woβmman (2003) established that this is an international phenomenon, with the family background the greatest influence on the students examination success. This is a known issue to the now Department for Education (DfE) (DfE, 2009), who in 2009 devised a deprivation weighting index to focus funding on schools with the greatest need, using the type and quantity of tax credits claimed in the catchments area to rank each school nationally (DfE 2009). Using this they found significant correlation between the deprivation of the school catchment area and GCSE results, reproduced in Figure 2.4, illustrating the effect of the student background on attainment.

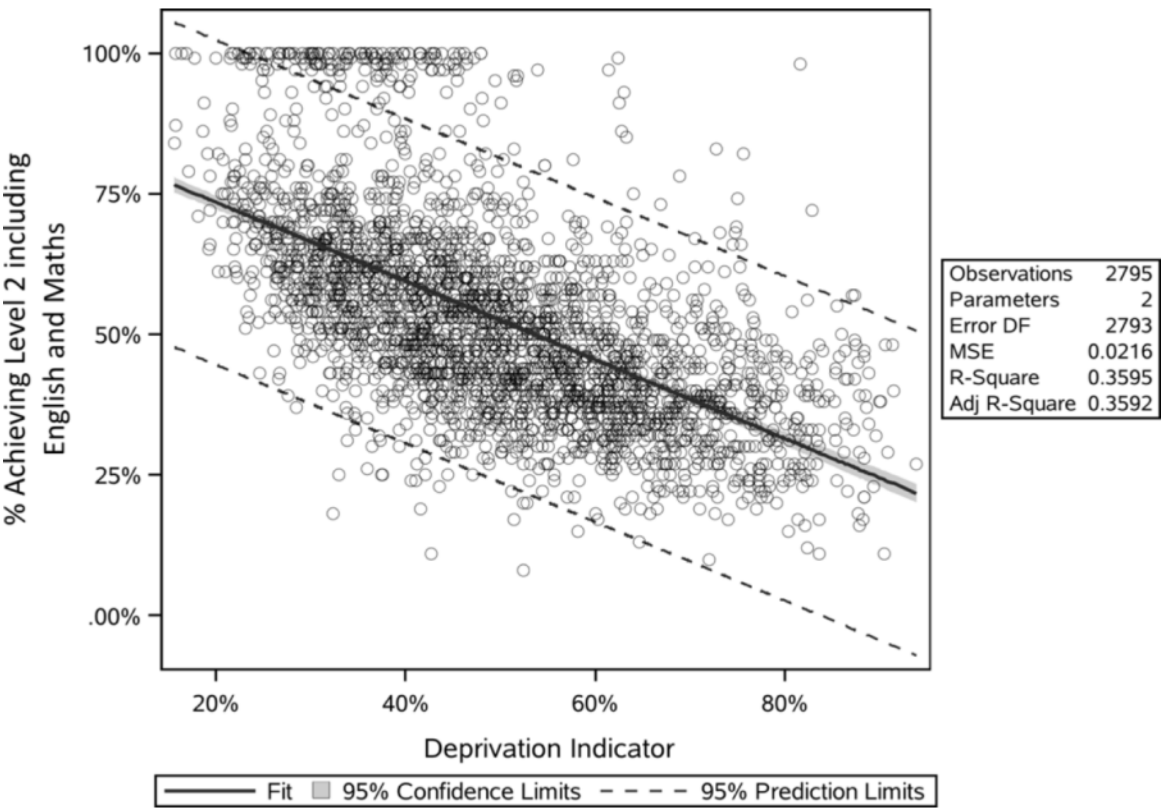



**Figure 2.4 – Graph showing the correlation between GCSE results (Level 2 attainment incl. English and maths) and DfE's deprivation indicator (adapted from the DFE (2009))**

The level of education the parents received was found to be one of the strongest factors in student performance, far greater than the teacher characteristics (such as education level or experience) or

[7] Trends in International Mathematics and Science Study, operated by Boston College's Lynch School of Education, and run in conjunction with the Progress in International Reading Literacy Study (PIRLS)

the institutional setting (e.g. the exam setting, curriculum decisions or budget responsibility) (Wößmann (2003, table 1)). The influence of the parents is linked to the amount of their involvement in their child's education rather than the level of education (Desforges & Abouchaar, 2003). Using the international PISA (OECD, n.d.-a) data, Fuchs and Wößmann (2008) further cemented the impact of the parents as the key differentiator among pupils, regardless of their nationality.

### 2.2.2 The School Educational Environment

Schools are complex entities and their main function of educating the next generation is an ambiguous description that does not define the various elements within the school. Capturing these elements has been a key part of the work of educationalists, understanding the mechanisms of a school and defining their outputs to enable greater understanding. This work has been an on-going branch of research since the late 1950s (Zullig, Koopman, Patton, & Ubbes, 2010), with many different names being used to define the concept (Libbey, 2004). For clarity, within this work the school educational environment will be referred to as the *school climate* as in Zullig et al.'s work and to ensure separation from the other aspects of this research (particularly the built environment).

Within Anderson's work (Anderson, 1982), the long history of the attempts to provide a universal school climate definition can be seen, with the early concepts arising from empirical and theoretical studies. However, within this study it is also clear that the work Tagiuri et al. (Tagiuri, Litwin, & Barnes, 1968) can be seen to underpin many studies, providing a broad and flexible framework that has been applied to many schools (most recently in the work of Owens and Valesky (2007) and Gislason (2010)). Tagiuri et al defined the school climate as four aspects that overlap to create the whole picture; *ecology* (the physical environment), *milieu* (student learning and motivation), *social system* (curriculum, teaching and control), and *culture* (staff values).

**Table 2.1 – Eight factors of student school climate found by Zullig et al, with variance and components (adapted from Zullig et al (2010))**

| Factor Number | Factor Description | Variance Explained | Exploratory Principal Components Analysis | Confirmatory Principal Components Analysis |
|---|---|---|---|---|
| 1 | Positive Student-Teacher Relationships | 27.6% | 0.88 | 0.91 |
| 2 | School Connectedness | 4.1% | 0.77 | 0.81 |
| 3 | Academic Support | 3.3% | 0.81 | 0.80 |
| 4 | Order and Discipline | 2.7% | 0.82 | 0.83 |
| 5 | School Physical Environment | 2.4% | 0.86 | 0.87 |
| 6 | School Social Environment | 2.1% | 0.84 | 0.82 |
| 7 | Perceived Exclusion/Privilege | 1.8% | 0.73 | 0.73 |
| 8 | Academic Satisfaction | 1.7% | 0.65 | 0.70 |

The four aspects of the school climate as defined by Tagiuri et al form a framework that assists the analysis, however, given the variance within the sector, relying on one framework (despite its prevalence) risks missing key aspects. Zullig et al (2010) identified the lack of consensus within the discipline and used the five most common school climate surveys within the USA[8] to analyse the different factors that exist within the school climate. They created a hybrid survey based on these five surveys, which were then applied to 2,049 students, and the results analysed using principal component analysis. This principal component analysis identified eight factors to the school climate (shown in Table 2.1) and the amount of variance explained by each factor. Within the

[8] The five surveys used were the San Diego Effective Schools Students Survey (ESSS), National Education Longitudinal Study (NELS), California School Climate and Safety Survey (CSCSS), the National Association of Secondary School Principal's Comprehensive Assessment of School Environments (CASE), and the School Development Program (SDP).

eight factors, the greatest variance is associated with the positive student-teacher relationship, accounting for 27.6%, but also of note is that the framework accounts for only 45.7% of the overall variance within the sample with the rest beyond capture by their questionnaire. These influences could include the current politics (Mahony & Hextall, 2013), deprivation (Collins, Kenway, McLeod, Australia, & Department of Education, 2000), and the families of the students (Desforges & Abouchaar, 2003). However, through these eight factors, and the associated questions, there is a testable framework to analyse the school climate.

**Influence of School Climate on Attainment**

Despite the evidence of large international studies that suggests that the parents hold the key to successful student education (see chapter 2.2.1), other studies have found that at a school level, the teacher performance becomes far more important. Wenglinsky (2002) used the National Assessment of Education Progress (NAEP) to explore the performance of the students, finding that teacher quality (education level and experience) is at least as important as the student background. Rowe (2003) argues that the studies focusing on the international data do not capture the classroom/teacher dynamic, highlighting that *instructional effectiveness* is difficult to capture in these international studies. Goe (2007) examined the contemporary literature on teacher quality and found that there was not one robust definition, but rather many valid versions. Within their work they highlight the link between teaching quality and the socio-economic situation of their school, suggesting that the two cannot be necessarily separated. Student engagement (as discussed in the school performance section earlier) may be a better measure of teacher influence, particularly whether it was felt that teachers cared about the students' performance (Ryan & Patrick, 2001), although the engagement definition has yet to universally adopted.

As with the teacher quality, the leadership of the school also has a direct influence on the performance of the students in the school, with the work of Wößmann and Fuchs (Fuchs & Wößmann, 2008; Wößmann, 2003) finding it more influential than personal characteristics of the teachers (except the negative impact of teaching unions). The Department for Children, Schools and Families (DCSF) and Day (Day & DCSF, 2009) looked into the effect of leadership in primary and secondary schools from the perspectives of pupils, teachers and heads. They found that there was a perceptible difference in student outcomes directly related to the leadership, although there was no direct measurement of student performance within this study. Seashore et al. (2010)

explored the different levels of leadership, from the senior leadership team to councils (or equivalent), finding that they all have an impact on the learning outcomes. They also highlight that, as with the teaching quality and students themselves, there is no one style that is universally successful, and instead it needs to be context aware.

### 2.2.3 Indoor Environmental Quality

Given the importance placed on the built environment by the government, particularly in the Building Bulletin series, it is important to examine the established links between education and the building. ASHRAE's Guideline 10-2011 (ASHRAE, 2011) splits the indoor environment into four factors; indoor air quality (IAQ), thermal environment, sound and light (ASHRAE, 2011, p. 3). These factors will be discussed in turn in the following sections, focusing on any links within the school environment.

**Indoor Air Quality**

The air within any space includes a mixture of different chemicals, as well as any number of particulates, and this poses a significant problem in the field of IAQ. Examining the impact of each of these constituent parts is clearly prohibitively difficult and producing guidance on acceptable concentrations within the school environment is consequently tricky. As such, the chemical composition of internal air tends to be overlooked, instead there is a focus on bringing in 'fresh' air from the outside to improve the internal air. Building Bulletin 101 (DfES, 2006) stipulates that there should be the capacity to provide up to 8 l/s/person of fresh air brought into any occupied space to ensure that the air quality remains acceptable. This stipulation of generic fresh provision allows the guidance to simply ensure that the IAQ remains acceptable without the complexity of the various components of air.

As a proxy for measuring the IAQ, Building Bulletin 101 (in common with many other publications) uses $CO_2$ concentration, recommending that it should not be over 5,000 ppm in any occupied teaching space and should be controllable to less than 1,000 ppm. $CO_2$ is regularly thought of as a good indicator of IAQ, representing the human influence on the space, with $CO_2$ a by-product of the metabolism of the people within a space. The actual amount of $CO_2$ produced per person depends on a range of factors, including activity, size and age, as discussed by Coley and Beisteiner (Coley & Beisteiner, 2002; David A. Coley & Beisteiner, 2011). In their 2002 study they found a typical adult produces 20.62 l/hour of $CO_2$, and child between 9.14 l/hour (for a student aged 4-5) to 14.36 l/hour (for students aged 12-13) in their study of 7 classrooms. These emissions rates are substantially less than the required 8 l/s/person of fresh air at 400 ppm $CO_2$ concentration (equivalent to 28,800 l/hour/person) in Building Bulletin 101, representing the importance felt of $CO_2$ as a proxy for air quality. Work by Bakó-Biró et al. (2012) linked declining IAQ and increasing $CO_2$ concentration (over 1,500 ppm) to reducing cognitive performance, a finding echoed by Myhrvold et al. (Myhrvold, Olsen, & Lauridsen, 1996), Coley et al (2007) and Shaughnessy et al. (2006). Similarly, Shendell et al (2004) linked poor IAQ and high $CO_2$ concentrations to increased absenteeism. Mumovic et al.'s (2009) study into air quality in recently completed schools found that three of the nine schools regularly exceeded the 1,000 ppm $CO_2$ recommended limit, and only one school out of the nine typically provided the recommended 8 l/s/person of fresh air, suggesting that new schools may still have problems with IAQ despite the awareness within industry. $CO_2$ has measurable effects on the occupants, but is largely odourless, with an odour detection level of 74,000 ppm (Van Gemert, 2006) so occupant sensitivity is largely through physiological effects rather than sensory detection.

A potential source of poor IAQ is external pollution from traffic, particularly given the current focus on external 'fresh' air as a remedy to poor IAQ. Ozone ($O_3$) and nitrogen dioxide ($NO_2$) are both readily associated with traffic pollution (see for example Clapp and Jenkin (2001)), and both are shown to have an effect on the health of occupants at high concentrations. For $NO_2$, peak concentrations are recommended to remain below 200 $\mu g/m^3$, with a maximum daily average exposure of less than 40 $\mu g/m^3$ to prevent adverse health by the World Health Organisation (WHO) (2010), although in Mendell and Heath (2005) and Chatzidiakou et al.'s. (Chatzidiakou, Mumovic, & Summerfield, 2012a) review of air pollutants, many cases of adverse health were noted at levels below those stipulated by the WHO. Notably the work of Pilotto et al (Pilotto, Douglas, Attewell, & Wilson, 1997) which found a link between high $NO_2$ concentrations (around 150 $\mu g/m^3$) and increased absenteeism. Ozone levels within schools have also been shown to have a strong relationship between increasing concentrations and increased health effects, with Chatzidiakou et al. (2012) summarising that increases of 30 to 100 $\mu g/m^3$ could increase the likelihood of illness related absenteeism by between 13% and 63% (Gilliland et al (2001)). This is clearly a large range, and the link to cognitive performance is under-researched, with little apparent beyond simple health based absenteeism. It should be noted that in the summary by

Chatzidiakou et al. (2012), measured ozone concentrations were typically in the order of 5–15 μg/m³, much lower than the WHO 8-hour exposure limit of 100 μg/m³ to prevent illness. For both $NO_2$ and ozone, the measured effects of increasing concentration were all below the guideline odour detection limits described by van Gemert (2006) of 350 μg/m³ and 100 μg/m³ respectively, suggesting that students within spaces will not be able to determine whether they are exposed to high concentrations of these gases. Any study linking external air pollution to the school performance needs to be aware that the pollution is location specific and might be masking the greater effects of the socio-economic background on the school performance.

Other contributors to poor IAQ are formaldehyde and VOCs and these can come from a number of sources within the environment, including cleaning materials, but also flooring and surface finishes (such as varnish or paint) that can *outgas* (or *offgas*) throughout the day. This is a notable difference to $CO_2$, which is largely created only during occupation by the occupants, so the highest concentrations of VOCs can be at the start of the school day before the fresh air systems are activated. VOCs have been tested within office environments and increased concentrations have been linked to reduced performance in cognitive tests under laboratory conditions Otto et al (1992), although Mendell and Heath (2005) note that other studies have struggled to find the same relationships. In Chatzidiakou et al.'s (2012) review of internal air quality, total VOC concentrations (TVOC) in other classrooms tend to be around 100-150 μg/m³. This range of concentrations tends to be much lower than the odour detection threshold, for example two common components of cleaning materials; isobutyl alcohol at 2,520 μg/m³ or trichloroethylene at 7,870 μg/m³ (Van Gemert, 2006).

Air-borne particulates are found in all but the most filtered air and are categorised by the diameter of the particle, commonly separated into three sizes; $PM_{10}$ (10 μm), $PM_{2.5}$ (2.5 μm), and $PM_1$ (1 μm) (Chatzidiakou et al. 2014). Daily average exposures of $PM_{10}$ over 20 μg/m³ are not recommended by the WHO (World Health Organization, 2010). Mattsson and Hygge's (2005) study into particulate air cleaning found limited improvement on memory recall in cleaner air, but no effect on other cognitive measures, with Mendell and Heath (2005) also not able to identify any significant impact on student performance in their literature review. However, there is clear evidence that particulates are harmful and can increase the likelihood of the illness-related absenteeism particularly once the lag between exposure events and possible ill-health are accounted for (Ransom et al. (1992), via Chatzidiakou (Chatzidiakou et al., 2012)).

A particular difficulty in assessing the influence of the IAQ in schools is related to the impact of the air pollution, notably when determining the health effects. In urban areas, such as London, air pollution events can and do occur throughout the year[9], and separating the effects of the limited exposure within the school compared to the wider environment is difficult to do. However, there is an important comment about the current assumption that bringing in external air is bringing in 'fresh' air. Many pollutants can exist at high concentrations outside, and bringing these into the classroom will not improve all aspects of IAQ.

Air quality and temperature are often linked, particularly in the perceptions of the occupants. Berglund and Cain ((1989) via ASHRAE (2011)) investigated the IAQ for different dry-bulb air temperatures and dew-point temperatures, finding as the air temperature increased, air quality satisfaction decreased. In a study on perception of specific VOCs by Fang et al (1999 via ASHRAE (2011)) showed that as the enthalpy of the air increased (loosely analogous to the temperature) the air quality was felt to be poorer, with no discernible difference between the different VOCs at 28$^{o}$C and 70% humidity.

**Thermal Environment**

The thermal environment is generally thought of as ambient dry-bulb air temperature, most notably within Building Bulletin 101 (DfES, 2006) which stipulates that the teaching spaces should meet two of the three criteria in Table 2.2. Rather than the simple temperature that is often used, thermal comfort is highly personal and relies on a number of factors that are embodied in Fanger's model used by ASHRAE Standard 55 (ASHRAE, 2013) and CIBSE's guide A (CIBSE, 2007). In addition, the more recent thermal comfort models also include an *adaptive* element, with the expectations of the occupants at the fore front, for example in CIBSE's technical memorandum 52 which relates the internal temperatures to the external temperatures. (CIBSE, 2013).

[9] London is monitored by Kings College London and reports on the annual performance are available here: https://www.londonair.org.uk/london/asp/reports.asp (last accessed 1st May 2016). Many monitoring sites in London exceeded $NO_2$ recommended annual means in 2014, but $PM_{10}$ levels were much lower.

Much of the research into the effect of thermal comfort on occupants, whether in schools or elsewhere, has been conducted in the Far East where high temperatures are a problem (for example the work of Wong and Khoo (2003)). Wargocki and Wyon (2007) investigated the effects of varying temperature on simple cognitive tests found that reduced temperatures, from 25ºC down to 20ºC, improved performance. However in their 2013 work (Wargocki & Wyon, 2013), they found that there is contradictory evidence to suggest temperature has a significant impact on the academic performance as long as the temperature remains within the broad bounds of 20ºC and 27ºC. Higgins et al (2005) and Woolner et al (2007) similarly found few robust links between academic performance and the thermal environment.

**Table 2.2 – Summary of thermal environment requirements stipulated within Building Bulletin 101 (DfES, 2006)**

| Criterion | Requirements |
|---|---|
| **A** | There should be no more than 120 hours when the air temperature in the classroom rises above 28°C per occupied school hours |
| **B** | The internal air temperature should be no more than 5°C above the external air temperature on average |
| **C** | The internal air temperature when the space is occupied should not exceed 32°C. |

**Access to Light**

Recommendations for lighting with new English schools is discussed by Building Bulletin 90 – Lighting Design for Schools (Department for Education., 1999), largely based on standards from the Commission Internationale de l'Eclairage (International Commission on Illumination, CIE). Within Building Bulletin 90 it is noted that where possible "*…schools should have natural lighting whenever possible*" (Department for Education., 1999, p. 15). To assist with assessment of daylighting in a space, Building Bulletin 90 uses the daylight factor metric, which is effectively the average percentage of external daylight the space receives during a uniformly overcast day. They define three daylight bands:

- Daylight factor over 5% for rooms to be considered day-lit

- Daylight factors between 2% and 5% will require additional lighting during Winter
- Daylight factors less than 2% will require frequent additional lighting

Within the new school building programme, the Priority School Building Programme (PSBP), daylight in schools is assessed using more complex Climate Based Daylight Modelling (Education Funding Agency, 2013). This shows the useful amount of daylight a space receives, overcoming the issue that greater daylight factors could be seen as better which could lead to glare issues.

Noting that the spaces will undoubtedly need electric lighting, BB90 provides minimum performance standards for each of the spaces regularly encountered in a school (see Table 2.3), based on those provided by CIBSE (CIBSE, 2007).

**Table 2.3 – Required artificial lighting levels for different school spaces as defined in Building Bulletin 90 (adapted from Department for Education (1999) table 6)**

| | Standard Maintained Illuminance (lux) |
|---|---|
| General Teaching Spaces | 300 |
| Teaching Spaces with close and detailed work (e.g.: art and craft rooms) | 500 |
| Circulation Spaces: Corridors & Stairs | 80-120 |
| Circulation Spaces: Entrance Halls, Lobbies & Waiting Areas | 175-250 |
| Circulation Spaces: Reception Areas | 250-350 |
| Atria | 400 |

Examining the literature regarding the artificial lighting of spaces finds that historically the research into the effect of lighting on people was from a medical perspective. This is best encapsulated in Wurtman's 1975 study into the body's response to light to ascertain the long-term effect of artificial lighting, surmising that "*We have been lucky, perhaps, in that so far* [artificial lighting] *has had no demonstrably baneful effects*" (Wurtman, 1975, p. 77). In fact this has been somewhat overturned by work such as that by Küller and Lindsten (Küller & Lindsten, 1992) who demonstrated significant changes in hormones in students depending on the type and quality of light provided.

The quality of internal lighting has been significantly investigated with a long history of reports investigating illumination levels, such as the work of Roethlisberger and Dickson into light levels that gave rise to the famous Hawthorne effect (Roethlisberger & Dickson, 2013), as well as the quality of the light itself. Berman et al (2006) found that for at higher illuminance levels (350 lux), higher temperature lighting (5500K) can improve visual acuity, although this improvement was not found as illuminance levels decreased. This study partly explains the improvements in oral reading fluency found by Mott et al (2012) when using higher colour temperature lighting. Studies by Knez (Knez, 1995) and Knez & Hygge (Knez & Hygge, 2002) found that higher colour temperature lighting also improved memory recall and problem solving. Hathaway (1995) found increased attainment in students exposed to higher temperature lighting in line with these studies, but also found improvements in attendance, potentially linked to the 'relaxing effect' noted by Dunn et al (1985).

Many of the studies into lighting temperature found that as the temperature increases there is an associated improvement in performance (whether visual acuity, memory recall, etc.) and given the high temperature of light from the sun it can be inferred that these effects will also be apparent were the lighting to be replaced with daylight. However, the effect of daylighting has additional benefits beyond simple acuity, with Heschong et al (2002) finding significant links between motivation in students and daylight availability. Despite this clear link, it is difficult to separate the daylight from the provision of a window and the associated views outside. Indeed, many other studies looking at offices have found the very presence of a window have had significant link to improvements in the work place, for example the proximity of windows (Yildirim, Akalin-Baskaya, and Celebi (2007) and Boubekri and Haghighat (1993)), or the naturalness of the view (Boyce, Hunter, & Howlett, 2003; Leather, Pyrgas, Beale, & Lawrence, 1998).

Despite the considerable amount of literature, there is still some debate on the importance of lighting in a more general regard, with Wu and Ng pointing out there appears to be little evidence for the standards put forward in much guidance (Wu & Ng, 2003). Boyce et al (Boyce et al., 2003) similarly found that there is no guarantee of improvement purely because of daylight as personal preferences for lighting can unduly influence any outcomes. Even in spaces where daylighting is considerable, the implementation may still cause issues, as Winterbottom and Wilkins (2009) found, noting the large variance in daylight quality and the potential for glare. The very nature of daylighting makes it location and season specific, for example the study by Kuller and Lindsten (1992) was undertaken over a winter in Sweden, where fewer daylight hours could be expected potentially skewing their data.

It can be seen that daylight is generally advantageous over artificial lighting, not least in terms of energy usage, but also in terms of school performance, as long as it does not cause glare. And where natural daylight it is not possible then high temperature lighting will provide the best compromise. However, further research into daylight within a school environment is needed as the existing research into offices cannot be directly applied, but rather only hint at what could be expected.

**Acoustic Environment**

Guidance for acoustics within the school environment falls into two general areas; reverberation and ambient noise levels. Building Bulletin 93 (DfES, 2003) sets out the requirements for the differing school areas (see a summary in Table 2.4), covering the length of reverberation times, upper limits for ambient noise levels (over a 30 minute average using A-weighting that gives greater weighting to higher frequencies (CIBSE, 2007)), tolerance of noise, and expected activity noise.

**Table 2.4 – Noise characteristics and reverberation times for different secondary school rooms as outlined in Building Bulletin 93 (adapted from Building Bulletin 93 (DfES, 2003))**

| Type of room | Room classification for the purpose of airborne sound insulation | | Upper limit for the indoor ambient noise level | Reverberation time (unoccupied) |
|---|---|---|---|---|
| | *Activity Noise (source room)* | *Noise Tolerance (receiving room)* | $L_{Aeq,\ 30min}$ *(dB)* | *RT60 (seconds)* |
| Secondary School: classrooms, general teaching areas, seminar rooms, tutorial rooms, language laboratories | Average | Low | 35 | <0.6 |
| Open Plan Teaching areas | Average | Medium | 40 | <0.8 |
| Open Plan Resource areas | Average | Medium | 40 | <1.0 |

Reverberation times need to be controlled within a classroom to ensure that the intelligibility of speech is maintained, with longer reverberation times creating overlapping syllables and hence reducing clarity of speech (Finitzo-Hieber & Tillman, 1978). Crandell and Smaldino (2000) noted that in particular the vowel sounds can cover the constant sounds if the reverberation times are too long. This overall reverberation time is given as the average of the reverberation time at three specific frequencies: 500 Hz, 1000 Hz and 2000 Hz (Association of Noise Consultants, 2011), as each frequency will behave differently within the space. While Crandell and Smaldino (2000) recommend examining a fuller spectrum (from 125 Hz to 8000 Hz), the research undertaken supports the 0.6 second reverberation time within classrooms (see the extensive list of supporting studies within Crandell and Smaldino (2000)).

Picard and Bradley (2001) conducted a review of the available literature to assess the then current understanding of noise in a learning environment. The aim of the paper was to produce a set of criteria that could be used as guidelines for school design. With this specific aim, they first evaluated the problems of the current building stock, finding ambient noise levels up to 37 dB above the agreed maximum of 35 dBA within the 17 different papers examined.

Picard and Bradley also closely examined the effects of this high ambient noise level, noting that the teachers' speech-to-noise (SNR) ratio is regularly below 10 dB. Speech-to-noise ratio governs the ability of the teacher's voice to be heard over background noises, which is shown in this paper to be closely linked to speech intelligibility and reverberation. From their analysis of previous studies, they posit that a 10 dB SNR is a reasonable minimum value for teachers to experience. At lower ratios, they note that many other studies have found 'vocal fatigue' in teachers, leading to voice disorders (Picard and Bradley 2001 p229).

Within Shield & Dockrell (Shield & Dockrell, 2003), they noticed that problems with memory and cognitive functions persist after chronic exposure to loud ambient noises. While the effect is not statistically significant, the implication that the home of the children has an impact raises two predominant concerns: that laboratory research needs to account for this variation in subjects, and that improving their home life may have improved their cognitive performances. Another aspect of this chronic exposure is the concept of noise tolerance, as found in the literature review by Stansfield & Matheson (2003). They found conflicting evidence that suggests people become tolerant of their acoustic environment, but other studies found that annoyance with the excessive noise does not subside. This could be applied to school design if, for example, the children live next to a busy road and their school is next to the same busy road then it is likely they will be less sensitive to the that specific noise source.

Additionally, a case study by Shield et al (2002) found that the type of ambient noise was important. In this study, the children responded better when the ambient noise was general noise rather than talking. This implies that it is not only the volume of sound, but also the information that the sound conveys. This finding is further supported by further findings in the Shield and Dockrell (2003) report regarding the effects of different noises (trains, planes and traffic) on cognitive and memory performance. Differences are noted between each noise source, suggesting that the type of noise may have significant impact on the learning environment. Kjellberg et al. (1996) examined the effects of noise in a working environment and similarly concluded that the type of noise was of high importance; with the predictability, control and requirement of noise central factors to the acoustic comfort.

### 2.2.4 Built Form/Aesthetics

The built form and aesthetics of school building design are areas that are in many ways less tangible than the environment, but the easiest to perceive as an occupant. For example an occupant can quickly establish if a building is run-down, but the quality of finish can be very difficult to quantify (although not impossible as Durán-Narucki (2008) showed). For this reason, much of the research relies on the occupants' perception of the environment, allowing them to rate the features that are important to them.

A clear exception to this method is the research surrounding use of colour within teaching spaces, where the colour can be definitively quantified. Wollin and Montague (1981) compared academic performance in a university in two different rooms; one brightly decorated with additional decorative items, the control room entirely monochromatic. They found that the students performed significantly better in the bright room and teaching staff were rated more positively. Woolner et al.'s (2007) literature review into the school environment found similar improvements as a consequence of using colours within classrooms, but noted that the effect of specific colours were less clear (and in some cases contradictory). A hint to the actual effector might be found within Durán-Narucki's (2008) work comparing the condition of school facilities against absenteeism, with better conditions linked to higher attendance in schools in New York. It may be that by simply showing care in the space is enough to trigger improvement.

Examining the effect of building layouts, Ahretzen and Evans (1984) looked at the number of walls for a teaching space against the opinions of the teachers and students. The students had no significant feelings towards the type of space, whether the space is more open or had more traditionally enclosed rooms. The teachers expressed mixed feelings towards the spaces, with the open spaces restricting their teaching methods, but also enabling greater interaction between teachers throughout the day. Moore and Lackney (1993) recommended that schools created “activity pockets” adjacent to a central teaching space, emulating open plan teaching styles seen later. Studies by Cotteral (1984) and Gislason (2009) support the use of open teaching spaces, with the additional supervision producing a culture that encourages the students, but only while teaching in a non-traditional manner that may not be familiar to many teachers.

Within the teaching spaces the layout of the furniture has been shown to have a direct impact on the teaching of the class and was researched by Betoret and Artiga (2004). They defined five different layout typologies for the classroom and found that the teachers’ pedagogical style had a strong relation to the attitudes of each layout. Martin (2002) similarly found that the layout of desks similarly assisted with some lessons, but raised significant questions about the awareness of the space by the teachers. Teachers were not generally aware of the influence of the layout on their lesson, but those who had greater control of their space have greater teaching satisfaction. Encouraging this flexibility Sime (1985, 1986) found that this is the key factor in creating a successful school, allowing the teachers to create the ideal space for their lessons.

### 2.2.5 Measuring the Built Form: Space Syntax

Simple measures to quantify the built form such as Gross Internal Floor Area (GIFA) and ratios (such window to wall ratios) are commonly used when discussing the built form, however these metrics fail to capture the actual layout of the building. Within Steadman’s extensive work into the changing built form, a mechanistic representation of the rooms has been developed that allows direct comparison between building forms (Mitchell, Steadman, & Liggett, 1976; Steadman, 2014), culminating in an architectural *morphospace*. This morphospace captures the relationships between the elements of the building, whether it is building elements such as walls, or the rooms themselves. This reduction of the built form to a simple number allows direct comparison between buildings and is particularly useful for evaluating evolutionary designs of buildings due to the way in which it encodes the information (Steadman, 2008). However, theses architectural morphospaces do not directly represent the building, only the selected aspects, limiting their applicability in real-world research.

In order to quantify the layouts of towns and cities, Hillier and Hanson's *The Social Logic of Space* (1984) matured the concept of *space syntax* from infancy into the full research area it is today. Although developed initially for analysis at the city scale, the concepts proved just as adept at quantifying the built form at a building scale, notably in the early work of Hillier and Grajewski ((1990), via Sailer (2010)). Using the tools developed by Hillier and Hanson, space syntax has been able to predict occupant movement within spaces, connecting the visual landscape with wayfinding (Hillier and Penn 1991; Hillier et al. 1993). This ability of space syntax to infer the movement within a space while quantifying the built form makes it a flexible tool.

Hillier and Hanson's space syntax hinged on the representation of the interconnection between the spaces, creating a distributed network (a graph) that can be analysed to expose the relationships between these spaces. Initially, this was simply through simple diagrammatic constructs (convex graphs), but this soon developed into *axial line* analysis, which explores the "*... full limits of visibility and permeability within the layout.*" (Bill Hillier, 2007, p. 98).

Despite work by Peponis et al (1998) and later Turner et al. (2005) to fully define a process for generation of the axial line map, the subtleties of the axial line map can be somewhat subjective, relying on the experience of the practitioner to capture the whole space accurately. Leveraging the importance of visibility within space syntax, Turner and Penn (1999) and Turner et al. (2001) introduced the concept of the visibility graph, which would become an alternative to the axial line analysis in contemporary space syntax analysis within buildings; *visual graph analysis* (VGA) (Turner 2003). Visibility graphs are created using a series of discrete isovists within a space, creating a network of nodes that represent the visibility of each point in the space, which can then be analysed, as shown in Figure 2.5. By creating an isovist at each node, a simple tally of node visibility can be created, counting each time the node was included within an isovist. At its most basic, this simple tally can give an indication of the visibility of the building/space, but large areas that contain a number of nodes will appear to be very visible, due to the sheer number of nodes within that space, potentially obscuring subtler effects on the visibility.

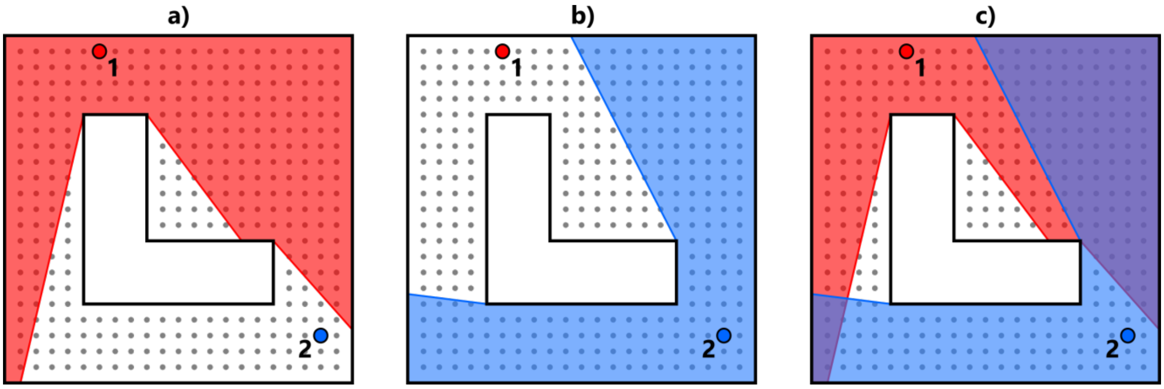



**Figure 2.5 – Illustration of 360° isovists from two points, a) showing isovist from point 1, b) showing isovist from point 2, and c) showing overlap of isovists from points 1 and 2.**

Given the strong relationship between the size of the space and the visibility, dimensionless measures of the space based on the visibility are necessary to enable analysis across the whole space and between buildings/spaces. Two commonly used dimensionless measures are integration and mean depth (also called mean shortest path length), both of which are used as initial tests of the viability of VGA (Turner and Penn 1999; Turner et al. 2001). Mean depth of VGA systems uses Hillier and Hanson's (1984) visual accessibility measure and extends it from axial line measures to a node based system as defined by Turner et al. This effectively represents the mean number of changes in direction a person would have to make to view every other point within the building, with lower values indicating a more open space with greater visibility. For example, in Figure 2.5, two steps are required to view point 2 starting at point 1, with those points visible from point 1 having a step depth of one. Integration builds on this step depth, normalising the step depth against the number of elements (Hillier and Hanson 1984), creating an abstract value, with lower values representing less visibility within the space.

Integration has been widely used in axial line analysis of buildings to represent the movement of people, including in schools. Pasalar (2004; 2007) studied four schools, using axial line analysis to understand the student movement and behaviour within the buildings, noting that as the number of building stories increased, the integration of those spaces decreased (from 1.497 for a single storey school to 0.986 for a four storey school) and consequently were less intelligible. Pasalar also monitored movement of students through the building, finding the highly integrated corridors had higher quantities of movement than less integrated circulation areas, with more frequent informal interaction between students noted in these spaces. Kishimoto and Taguchi (2014) studied 76 primary schools in Japan, combining integration and questionnaires to explore the influence of the spatial configuration on teaching, with integration shown to be negatively correlated to the flexibility of teaching styles. This suggests that more visibly accessible spaces provide greater support for a range of teaching styles. Similar studies using space syntax to assist in analysing the utilisation of buildings have been undertaken, notably for museums (Turner et al. 2001; John Peponis et al. 2004; Tzortzi 2004), and offices (Sailer, 2007, 2010). The work of Sailer in particular examines the movement and interaction of workers in offices, identifying that although integration and mean depth can be predictors of areas of high movement, notable exceptions do occur, with these spaces identified as *attractors*. These attractors, such as tea points, can have an over-riding effect on any configurational logic of the space, creating a distinct flow of movement motivated by necessity (Sailer 2010 section 7.1.2).

An additional measure used within the space syntax community is the measure of *intelligibility*, which uses the connectivity[10] and the integration of the building to create an overall measure of the building. The $R^2$ value of the regression between the connectivity and the integration is the quoted value of the building's intelligibility, and corresponds to the ability of a person within the building to understand and navigate the spaces, using the built form as guidance (Penn, 2001). This adds an additional layer of information to the built form, with Bafna (2003) likening this to uniqueness of the space that can help guide visitors over and above an intuitive layout. Pasalar (2004) measured the intelligibility of four schools, with the single storey buildings having a much higher intelligibility score (0.5772) than the more complex, two-storey school (0.1715), with the added complexity of the two-storey school making the intelligibility lower than the four-storey school also studied (0.1954).

## 2.3 Integrated Methods of Analysing the School Environment

While a majority of research in the school and its environment has focused on singular aspects, work has been done to create a holistic view of the impact of the built environment. These works fall into two general types; literature reviews and multi-method studies, with few of the latter. Perhaps the most widely read literature review is by Higgins et al (2005). Reviewing the contemporary research, the definitive links between environment and school outcomes were highlighted, summarised in Table 2.5. Also apparent in Table 2.5 are the large gaps in much of the

[10] Klarqvist (1993) defined connectivity as "…measures the number of immediate neighbours that are directly connected to a space".

research, a consequence of the large number of variables and outcomes. Focusing on the Indoor Environment Quality (IEQ), Mendell and Heath (2005) conducted a similar literature review of the importance of the built environment on the school performance. Their study also expanded to include the wider field of office performance as an indicator of potential similar school relationships. Similar to the Higgins et al study (2005) they found that there are significant gaps in research that prevent causal relationships to be fully defined, but did find partial causal relationships between poor IEQ and attendance that would have a consequential influence on attainment (Malcolm, Thorpe, & Lowden, 1996).

Within their study, Higgins et al (2005) note that although links between the internal environment and the school outcomes were found, the clearest evidence is that "*extremes of environmental elements… have negative effects on students and teachers*" (Higgins et al 2005, page 6). They go further to announce that the very process of changing the environment is the catalyst into any improvements in school performance. This is echoed in the follow-up paper by Woolner et al (2007) that stresses the need for change as a chance to facilitate improvements through careful consultation with the existing school staff.

There have been few studies that have attempted to investigate the whole school environment beyond a literature review, largely caused by the difficulty of quantifying the many aspects of the environment. Barrett et al. (2013) have conducted a holistic analysis of 34 classrooms across 10 primary schools in England. Within their study, they measured 10 aspects, of the built environment:

- Light
- Sound
- Temperature
- Air Quality
- Choice
- Flexibility
- Connection
- Complexity
- Colour
- Texture

These 10 factors were measured using either assessments by the research team, particularly the qualitative aspects such as colour, interviews with teaching staff and spot measurements of environmental factors. These factors were compared to the progress the students made over the course of a year, as reported by the teachers, using a multi-level model. Their multi-level model found that the environmental factors accounted for 25% of the overall variance in attainment, with the connection (circulation), colour, complexity (variance in classroom spaces) and flexibility the most important environmental factors. There are a number of concerns regarding the methodology behind the measurements of the school environment, with a focus on simplicity rather than capturing the true built environment. Notably the spot measurements of the internal environments do not necessarily represent the average classroom environment, with the environment significantly changing throughout the day and from season to season (see Mumovic et al.'s study into air quality in school for example (Mumovic et al., 2009)). There are also concerns over the quantification of the building form, with the use of circulation breakout areas seen as a negative effect on the school despite varied learning zones seen as a benefit to the school. This study has shown the ability to analyse the holistic environment, but in the process made simplifications of the school environment to enable the analysis. In addition, there is little consideration of the school climate, with the teaching influence effectively side-lined within the work.

**Table 2.5 – School environment aspects and their relationship with the school (adapted from Higgins et al 2005)**

| | **Temperature /Air Quality** | **Noise** | **Light** | **Colour** | **Other school build features** |
|---|---|---|---|---|---|
| **Attainment –** improvements in curriculum attainment measured by standardised tests or exams, or as monitored by teacher observation | Poor internal air quality – low attainment | Reading scores, pre-reading skills, general attainment | Link claimed | | Outdoor spaces, pathways; What is 'good enough'? |
| **Engagement –** improvements in levels of attention, more on-task behaviours observed, decrease in distracted or disruptive behaviour. | Air conditioning noise may distract | Attention and distraction; Time lost through noise interruption, Internal noise | | | |
| **Affect –** improvements in self-esteem for teachers and learners, increased academic self-concept, improvements in mood and motivation. | | Annoyance; Learned helplessness | | Children want colour; High hopes but no coherence | Conflicting evidence on ceiling height |
| **Attendance –** fewer instances of lateness or absenteeism | Conflicting evidence | | | | |
| **Well-being –** impacts on the physical self, relating to discomfort as well as minor and major ailments. | Asthma; allergens; poor ventilation – build-up of pollutants, $CO_2$, etc. | Some suggestion of other physical effects (e.g. raised blood pressure) | Eyestrain, headaches, fatigue; Perhaps weight gain, dental cavities | | |

## 2.4 Summary

Within the literature review, there are two clear patterns; previous studies have tended to look at each aspect in relative isolation, and that there is little consensus on the underlying framework for the school climate. Given the complexity of schools, these two patterns should not be surprising, but it has clear implications on the methodology for this body of work. This research needs to include all the environmental measures described to be able to understand their interaction, and any school climate analysis should not rely on one definition of the climate, instead it should be analogous to the many definitions.

*School performance is widely defined as attainment and absenteeism, but need to used carefully.*
Assessing the importance of the school environment requires an understanding of the outcomes of a school. Looking at the performance of schools at a national level, the performance metrics are restricted to those collected centrally by the DfE, predominantly attainment (GCSE exam performance) and absenteeism. School performance in the context of this work will refer to attainment and absenteeism, aligning with the widely-used metrics. However, comparisons between schools will be very difficult given that the school performance is closely related to the socio-economic context of each school. Within the school-level hybrid, measures can be incorporated, such as student engagement, which represents the more holistic outputs of the school. In order to truly capture the whole school environment, a mixture of both of these methods need to applied.

*The recent Building Schools for Future programme represents an opportunity to see the changes to a school in a new building.*
In order to capture the influence of the built environment at a national level, it is necessary to undertake a high level analysis examining the influence of the new Building Schools for Future programme on the school performance. These new buildings represent the best recommendations for the internal environment and any change as a consequence of the new building should be clear.

*Various aspects of the built environment have a demonstrable impact on the educational performance*
Through previous studies, temperature, air quality, acoustics, daylight, aesthetics, and building layout have all been shown to have robust links to the school climate and/or the student performance. While a national level study can capture the general trends, it will be unable to determine the changes to the internal environment that may have caused any observable trends. To understand the influence of the built environment on the school/student performance, the environment itself needs to be measured and quantified.

*Each aspect of the built environment has traditionally been measured independently missing any interaction between different aspects of the school*

Given the complexity and number of environmental variables within a school, it is not surprising that previous studies have focused on the impact of one part of the built environment on the school/student performance. However, by using a mixed-method approach, each of the aspects of the built environment can be measured to create a full picture of the environment the school operates within and identify any interaction between them.

*Defined aspects at the school level have a demonstrable influence on school performance*

The literature review has focused on the influence on the school performance from the various aspects of the school. This has focused on influence on three areas of student performance: social-interaction, perception and the attainment. These are summarised in Table 2.6, Table 2.7, and Table 2.8.

**Table 2.6 – Summary of influences on the social-interactions of the students**

| | Aspect of School | Impact | References |
|---|---|---|---|
| Social Interaction | Lighting and daylight | Reduced absenteeism linked to higher temperature lighting | Hathaway (1995) |
| | | Higher motivation linked to daylight. | Heschong et al (2002) |
| | Indoor Air Quality | Increased absenteeism linked to high $CO_2$ levels. | Shendell et al. (2004) |
| | | $NO_2$ levels over 150 μg/m$^3$ correlated to increased absenteeism | Pilotto et al (1997) |
| | Socio-economic background | Variation in family background of students linked to variation in absenteeism | Attwood and Croll (2006) |
| | Teacher Quality | Increasing teacher concern over students shown to improve student engagement | Ryan and Patrick (2001) |
| | Circulation spaces | Well-connected corridors linked to greater informal student interactions | Pasalar (2004, 2007) |
| | | Physical layout of building may not dictate how and where people congregate, instead guided by necessity | Sailer (2010) |

**Table 2.7 – Summary of influences on the student perceptions of their environment**

| | Aspect of School | Impact | References |
|---|---|---|---|
| Perception | Lighting and daylight | Higher temperature light linked to 'relaxing effect' in offices | Hathaway (1995) |
| | | Influence of daylight linked to personal preferences, season, and effective management of light | Wu and Ng (2003), Boyce et al. (2003), Winterbottom and Wilkins (2009), Küller and Lindsten (1992) |
| | Noise and acoustics | Type and predictability of noise influences acoustic comfort | Standfield and Matheson (2003), Shield et al. (2002), Kjellberg et al. (1996) |
| | Indoor Air Quality | $CO_2$, $NO_2$, $O_3$, and VOCs odour detection limits are above cognitive impairment levels | Van Gemert (2006) |

**Table 2.8 – Summary of influences on the student attainment performance**

| | Aspect of School | Impact | References |
|---|---|---|---|
| Attainment | Indoor Air Quality | Increasing $CO_2$ concentrations over 1,500 ppm linked to reducing cognitive performance | Bakó-Biró et al. (2012a), Myhrvold et al. (1996), Coley et al. (2007), and Shaughnessy et al. (2006) |
| | | Increasing VOC levels have mixed links with cognitive performance | Otto et al. (1992), Mendell and Heath (2005) |
| | | Reduced PM levels have weak links with memory recall, but with mixed results in other studies. | Mattsson and Hygge (2005) |
| | Thermal Comfort | Temperatures below $27^0$C correlated to improved cognitive performance, notably lower temperatures, but with mixed results outside of hot climates. | Wong and Khoo (2003), Wargocki and Wyon (2007 & 2013). |
| | Lighting and daylight | Increased light colour temperature (5500 K) improves visual acuity, memory recall and problem solving | Berman et al. (2006), Mott et al. (2012), Knez (1995), Knez and Hygge (2002), Hathaway (1995) |
| | | View availability and naturalness linked to workplace improvements in offices | Yildirim et al. (2007), Boubekri and Haghighat (1993), Leather et al. (1998), Boyce et al. |

| | Aspect of School | Impact | References |
|---|---|---|---|
| | | | (2003). |
| | Noise and acoustics | Teachers' speech to noise differences of less than 10 dB prevents effective communication | Picard and Bradley (2001), |
| | | High ambient noise levels linked to declining cognitive and memory | Shield and Dockrell (2003) |
| | Socio-economic background | Increased financial difficulty of family strongly linked to declining exam performance | Goldstein and Thomas (1996), Goldstein and Spigelhalter (1996), DfE (2009), Wößmann (2003) |
| | | Increasing levels of parental education linked to improving academic attainment | Wößmann (2003), Desforges and Abouchaar (2003), Fuchs and Wößmann (2008) |
| | Teacher Quality | Improving teacher quality directly increases student attainment. | Wenglinsky (2002), Rowe (2003) |
| | | Context aware leadership at every level improves student outcomes | Wößmann (2003), Fuchs and Wößmann (2008), Day and DCSF (2009), Seashore et al. (2010). |
| | Classroom layout | Ability of teacher to alter layout to suit lesson linked to increasing teacher satisfaction | Martin (2002), Sime (1985, 1986) |
| | | Increasingly visible teaching spaces able to support greater range of teaching styles | Kishimoto and Taguchi (2014) |

# 3 Methodology: Development and Analysis of the Unified School Database

In the previous chapter, the complexity of the school environment was discussed at length, with the outcomes of each school an interaction of not only the built environment, but also the manner in which the school is run. In order to capture the full picture of secondary schools in England, this body of work has two distinct, but complimentary, approaches;

- Top-down, national level investigation into the performance of schools in new buildings through creation of large database
- Bottom-up, case-study looking in-depth at the particulars of each school

The interaction of these two sections of the research are illustrated in Figure 1.1, with the national level database forming an overall understanding of secondary schools, and the school-level case studies illuminating the particular aspects of the school climate. This chapter, and the following results chapter, will look solely at the work into the national-level investigation, starting with the methodology.

## 3.1 Introduction

Aiming to analyse the national secondary school system necessitates the creation of a database of appropriate data, capturing the pertinent data in a readily-interrogatable structure. In order to understand the schools, the database needs to hold data at an individual school level, with the focus on performance and the underlying background data for the school. This school level data format represents the best compromise of detail and accuracy, with the higher level datasets (such as by local authority or county) missing the details of each particular school, and pupil level data necessarily falling into groups for each school. This is reflected in the manner in which the Department for Education (DfE) records data for each school, with school averages used rather than pupil data. Despite the DfE collecting considerable data on each school, the data is split across different datasets and is very rarely analysed beyond the specific dataset function (attainment for example). By merging these disparate datasets together, a complete picture of the school can be created and analysed.

With the Building School for the Future (BSF) programme in England and Wales, the government have produced an opportunity to examine the differences between school performance[11] in new and existing buildings. To capitalise on this opportunity, the database needs to be able to longitudinally represent the schools through their transition to new buildings. As noted in the literature review, the performance of each school is recorded annually, focusing on the exam results, which would enable the school performance trends to be examined year-on-year. As such, the database will need to be able to store data each year, for each school. As with the different datasets for each school, historic data is rarely joined together to create a longitudinal understanding of a school[12]. This is simply implemented though the creation of a long database, with each record representing one year of data for one school, and each school appearing repeated times, once for each year in the dataset. This retains the structure for simple analysis, but also allows extensibility, with new records simply appended to the end of the database with the year incremented.

## 3.2 Data Collation and Cleaning

With the focus on the performance of the schools in England, the DfE are the source of a majority of the data within database. As noted above, the DfE already collect data at a school level, greatly simplifying the procedure for importing into a central database. The academic performance of each school is contained within a single database for each academic year and is widely available (DfE, n.d.-b). In addition to the academic performance of each school, the DfE also hold details on the location, the demographics, financial spending, and deprivation at the schools, providing key background information (see Table 3.1 below for a breakdown of each dataset). These datasets are all publicly available for each year, creating a large amount of data per school, identified by a school specific unique reference number (URN) and local authority establishment number (LAEstab). In addition, all the DfE datasets were available for many previous years, excepting the Edubase extraction, which updated rather than a new one produced each year. DfE datasets are

[11] As noted in Chapter 2.4, school performance in this case is constrained to attainment and absenteeism as these are the available metrics at a national level.

[12] One notable exception is the attainment, where certain key figures for the previous three years are often included.

subject to an audit process to ensure data validity, comprising internal review by the DfE and confirmation by the school prior to public release ensuring that the data is robust[13].

**Table 3.1 – Table of data sources, available years and data descriptions**

| *Data Set* | *Contents* | *Years available* | *Source* |
|---|---|---|---|
| Attainment/ Performance | *School-wide exam results and absenteeism (Level 2, Level 1 & Total Absenteeism only used)* | *1999-00 to 2011-12* | *DfE* (DfE, n.d.-b) |
| Consistent Financial Reporting | *Financial data for each school, broken down by specific uses.* | *2003-2012* | *DfE* (DfE, n.d.-b) |
| Deprivation | *Deprivation index for each school* | *2008-09 to 2011-12* | *DfE* (DfE, n.d.-b) |
| Display Energy Certificate (DEC) Data | *Annual energy consumption for each school (both electricity and heating), floor areas and internal environments types* | *2008-09 to 2011-12* | *Landmark Information Group* (Landmark, n.d.) |
| Edubase Extraction | *Background school data, including addresses, postcodes, unique reference numbers, and open/close dates* | *2012-13* | *Edubase website* (DfE, n.d.-a) |
| School Building Survey | *Data regarding the BSF schools; completion date, scale of works, and BREEAM rating* | *2009-10* | *DfE* (DfE, n.d.-b) |
| School Characteristics | *Breakdowns of the school staff/pupil numbers and demographics* | *1999-00 to 2011-12* | *DfE* ((DfE, n.d.-b) |

Despite the wealth of information from the DfE regarding the school performance and background, there is very little data held about the actual buildings. The Partnership for Schools (PfS), now the Education Funding Agency (EFA), provided data from an Asset Management Programme (AMP) conducted in 2006, with data from academic year 1999-2000, and limited data from 2004 to 2006. This AMP data incorporated figures about the building (floor area, swimming pool, building exposure) and total energy and water usage. While this is invaluable, the age of the data prevents any meaningful analysis of the current state of the secondary schools in England, as such an alternative source of building information was found in the Display Energy Certificate (DEC) data base held by Landmark Information Group on behalf of central government. DECs display the annual energy usage on graded scale, from 'A' to 'G', are to be prominently displayed

[13] The DfE data release procedure can be found here: https://www.gov.uk/government/publications/school-performance-tables-how-we-report-the-data/school-performance-tables-how-we-report-the-data (last accessed 12/01/2017).

where visitors to the building can see them. These certificates are required by all public building over 1000 $m^2$ since their introduction in October 2008 (reducing to 500 $m^2$ in October 2012), with renewals every year, presenting a valuable source of building specific data. Each DEC is created by certified assessor using the methodology from CIBSE's Technical Memorandum 47 (CIBSE, 2009), ensuring comparability between DECs, and hence comparability between schools.

As one of the aims of this database is to enable the longitudinal analysis of school performance, the annual data had to be collated together for each school. With the earliest building specific data from the AMP dataset, this was used to choose the initial year for the database; academic year 1999-2000. The availability of each source dataset varied between years, with the years used shown in Table 3.1, and the final year used for analysis as academic year 2011-12. It should be noted that the Edubase extraction gives overviews of many of the school features (such as contact details) and only the most recent extraction has been used as no historic data is available. Similarly, the school building survey only captures the state of investment in the school building stock at one particular time, as such the most recent version available has been used; from academic year 2009-10. This dataset only includes school building projects where funding has been assigned and the work has started, ensuring that those cancelled with the change in government were not included. Only those identified as being more than 80% refurbished, including complete rebuild, have been incorporated to ensure that the change of building is as total as possible. The deprivation index, as briefly noted earlier, is a normalised percentage rating between 0 and 100 that identifies the deprivation of the school catchment area based on the type and quantity of tax credits claimed within this area as defined by the DfE (2009). This was only developed in 2008-09 and has been used up until academic year 2011-12, prior to this there was no unified indicator of the deprivation of the school, relying on more complex non-unified measures.

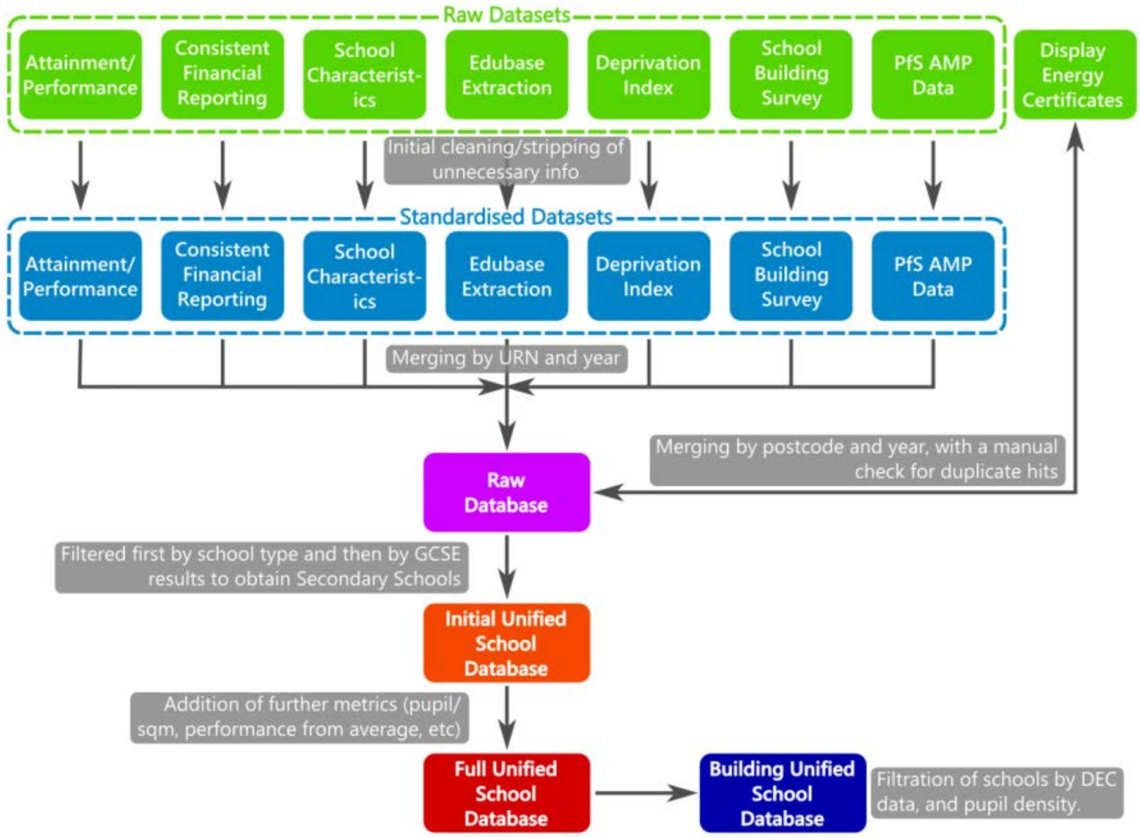



**Figure 3.1 – Graph data merging steps from raw data to final database (note the DEC data cleaning has not been shown here for simplicity)**

Data provided by the DfE was merged using the unique reference number (URN), creating a record for each year, for each school. This URN is persistent between years, serving to allow comparisons between years. Within the raw datasets, a number of records exist that are not pertinent to the overall analysis, such as primary schools and Special Education Needs (SEN) schools, as well school data that contains errors. Following the merging process (shown in Figure 3.1) a data cleaning exercise was undertaken to ensure data validity, using the following steps:

- Schools classified as primary, middle deemed primary, middle deemed secondary, or SEN specialist were removed
- All schools with no recorded GCSE data were removed
- All schools with zero absenteeism were removed
- Addresses with multiple records in a year were removed for that year

Given the emphasis on creating an all-encompassing dataset of English secondary schools, the cleaning of the unified school database has been aimed at removing misleading schools, rather than specific records. Instead, the dataset is filtered prior to analysis on the specific data relevant to the analysis (such as pupil numbers for example) creating the largest possible dataset and maintaining a broad range of applicability. Throughout the analysis of the dataset detailed in the following sections, only non-zero records were used in the analysis. This merged data gave rise to a varying number of records per year, both before and after cleaning, as shown in Figure 3.2. The full list of variables can be seen in Appendix A.

The DEC data was first filtered for those identified only as secondary schools within the DEC dataset, then filtered again based on the values for energy given in each record, using the criteria set out by Bruhns et al (2011):

- *Total Useful Floor area > 50m2*
- *Rating > 5 and< 1000 and not 200 (the default value given to a building with insufficient information available to produce a reliable assessment)*
- *Energy use index for heating (EuiHtg - kWh/m2) >0*
- *Main Heating Fuel (MHF) not electric*
- *Number of benchmark categories > 0 (i.e. at least one good benchmark category)*
- *Where a property had multiple DECs (as indicated by multiple DECs for a single Unique Property Reference Number – UPRN), the one with the latest end date for its consumption data was used. If there were multiple records with the same end date, the latest in the data (as it arrived from Landmark, indicated by row count) was used.* (Bruhn et al. 2011, p 9-10)

In order to merge the DEC data (with data from academic year 2007-08 to 2011-12), the postcodes and DEC lodgement date were used to find the correct school and academic year (taken as the year with the greatest overlap with the reported year of energy data). In instances where more than one DEC record was lodged per year per school, an average has been taken for the energy data. Where the heating/ventilation system is different between DEC records for the same academic year (particularly where the school is formed of more than one block), the internal environment is taken from the DEC with the largest area, or the latest record for that year if they have the same area. Following the merging of the data, between 850 and 1200 schools were successfully joined with their DEC data within the database (see Figure 3.2 for actual numbers per year). It should be noted that very few DEC records for the academic year 2009-10 were contained within the central dataset, as can be seen in Figure 3.2.

Using the cleaned dataset, national averages for attainment and absenteeism were found to enable creation of normalised attainment and absenteeism figures. This removed the annual trends that exist within the English educational system, allowing each school to be robustly examined for year-on-year performance with little influence of the external exam trends. It should be noted that to make interpretation of results easier, the absenteeism has been normalised with lower than average absenteeism shown as positive values, rather than negative values. Where direct comparison between schools needs to be made, the socio-economic background has been incorporated into the attainment figures by using the deprivation index[14] as a weighting (see Figure 2.4 for correlation). This has not been applied to the absenteeism figures due to the poorer correlation between the two. Where longitudinal performance is to be undertaken, comparing schools directly against each other, the normalised performance change relative to the previous year has been used, ensuring continuity of the socio-economic background of each metric as well as the national trends of attainment and absenteeism.

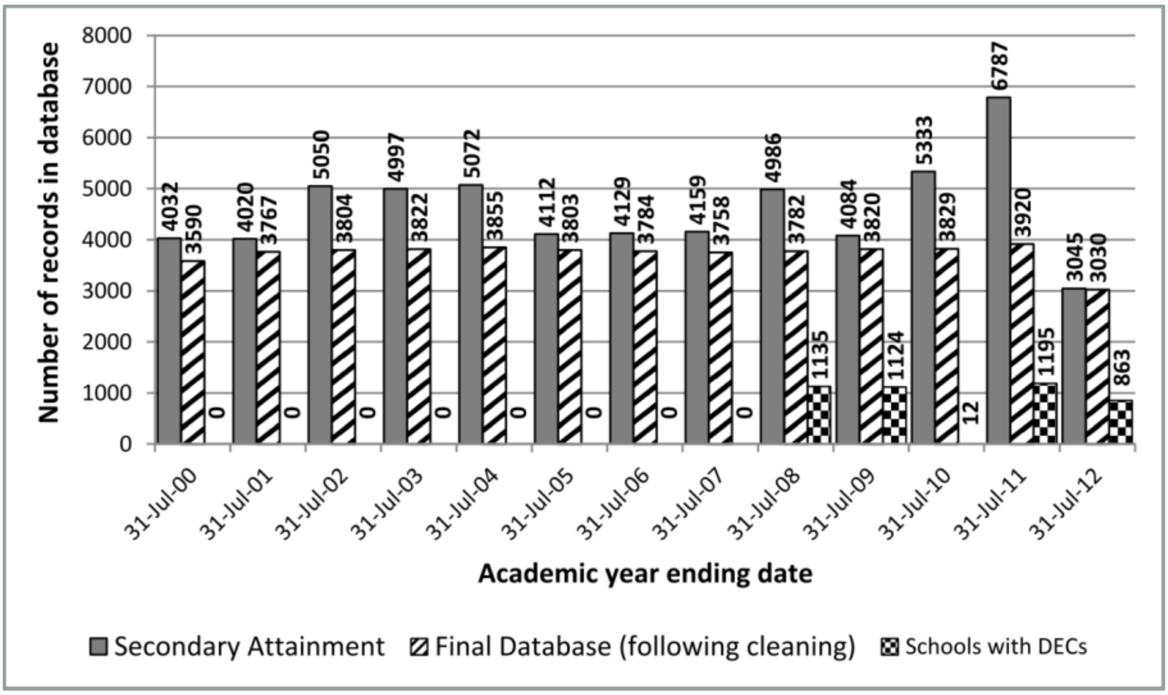



**Figure 3.2 – Numbers of records in each year within the unified school database, before and after cleaning**

Once the construction year was identified from the school building survey dataset, it was possible to identify the corresponding academic year, taking the 1st February as the mid-point of each

[14] A composite of the tax credits claimed by the parents of the students attending the school

academic year and hence the cut-off for the school building influence. In practice, most building open dates were quite distant from this cut-off date, with openings typically matching up with the start of the academic year (54% opening in September, and 78% opening between September and the end of January). The number of schools opening per year is shown in Figure 3.3, along with the number of DEC records available per year pertaining to the new buildings built up to that year.

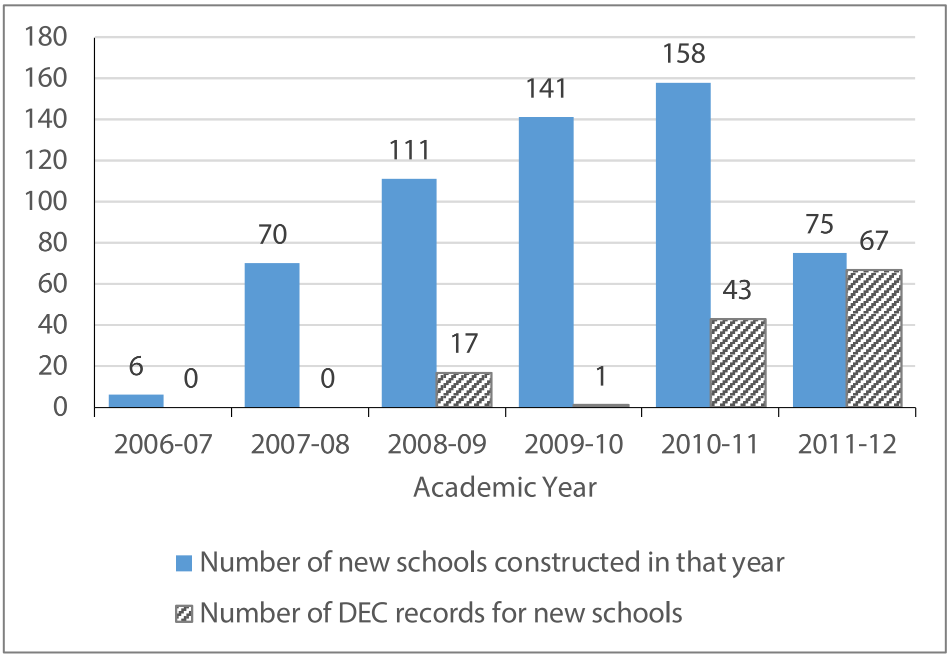



**Figure 3.3 – Graph showing number of schools constructed in each year, with the corresponding number of those schools that have DECs within the database**

## 3.3 Methods of Statistical Analysis

Using the unified school database, there are many investigations into the school climate that are possible, and it is intended that the database act a start point for future investigations into schools. Through this body of work, a number of different investigations into the performance of schools will be undertaken, evaluating the academic performance against the building.

### 3.3.1 Energy performance of schools

With all energy use in the built environment, benchmarking is widely used to understand whether usage is typical or atypical. This is very much true for schools, but schools have a very well defined output (education) that may provide an insight into how they operate and hence explain any deviations from the benchmark. As discussed earlier, directly comparing schools does not capture the socio-economic factors surrounding their situation, but there is a strong relationship between the deprivation factor of the school and the attainment (see Figure 2.4). This is used as a weighting attainment factor for the attainment, enabling direct comparison between schools. The deprivation weighted factor can be thought of as how hard the school works to overcome the socio-economic situation of their catchment.

The energy data from the DECs has a similar issue of local effects, with heating fuel use affected by the average weather conditions of each school. To compensate, degree day correction was used following the methodology in CIBSE's TM 41 (CIBSE, 2006), using local degree days from Vesma (Vesma, n.d.). This was applied using the degree day reference figure of 2,021 as used within the TM46 methodology (CIBSE, 2008), to give a simple correction factor to apply to each school. Electricity usage was not corrected, although an argument could be put forward for increased lighting use in the northern areas of England, Godoy-Shimzu et al.'s (2011) work showed little correlation between climate and the electricity use of schools.

With the deprivation-weighted attainment and absenteeism, the influence of the school academic performance was compared to the energy usage using a simple correlation and tested using the ANOVA test. Using the degree day-corrected energy data for each school, the new schools built under the BSF were then compared to the existing school buildings to examine the relative energy performance of the two school sets. This exposed the energy efficiency of the new buildings compared to the existing buildings. To assist in visualising this difference, the cumulative frequency diagrams used Hong et al (Hong, Paterson, Mumovic, & Steadman, 2013) have being re-used as a basis, with a two-tailed t-test used to test for significance between groups.

### 3.3.2 Influence of the changing school on academic performance

In order to understand the influence of the new school environment, a simple separation of the school states was undertaken manually, identifying four key stages of the new schools during this study:

I. The initial state (taken as the earliest record of the school building during the study period)
II. Original school type and a new school building (with the school type referring to community, voluntary aided/controlled, academy or specialist college)

III. Change in school type but original school building

IV. Change in school type and new school building

The change in normalised school performance between these states for each school was then tested using a Wilcoxon signed-rank t-test that evaluated the difference in means between two states (Field & Miles, 2010, Chapter 15.4.1). By assessing the change from the initial state, I, to the other states, the change in state that causes the greatest improvement was shown.

### 3.3.3 Exploration of academic performance before and after new building

Fully exploring the longitudinal performance of the BSF schools requires using the change in normalised performance and an index identifying the years before/after the new building. In order to determine whether the new school building had an impact on the school performance, a regression discontinuity analysis has been undertaken on those schools that have at least three years of occupation in the new school building, furthering the KPMG analysis (Rintala and Griggs, 2009). A regression discontinuity analysis focuses on the change in regression following an intervention and was introduced by Thistlethwaite and Campbell in 1960 (Thistlethwaite and Campbell (1960) via Schoeneberger (2011)). Largely overlooked until more recently, the key benefit of this type of analysis is the ability to determine whether an intervention made a difference, largely regardless of the sample used. A good example of the use of regression discontinuity analysis is by Ludwig and Miller (2007) in their revisit to the USA's scheme to improve health and schooling of children that received grants due to their level of poverty. A clear improvement for those children benefiting from additional funding was found by evaluating the difference between those that received funding and those that did not, indicated by the change in intercept and gradient of the regression line.

### 3.3.4 The effect of the internal environment

Using the Display Energy Certificate (DEC) data merged with school database, the internal environment variable (describing the heating/ventilation system) was used to compare the school performance, categorised as:

- Air Conditioning
- Heating and Mechanical Ventilation
- Heating and Natural Ventilation

- Mixed Mode

It should be noted that mixed-mode with mechanical ventilation or natural ventilation have been grouped together as "mixed-mode", reducing the ambiguity associated with defining the predominant ventilation strategy. In addition, by grouping the mixed modes together, there is an increase in the likelihood of finding significance during analysis. Should significance be found, then this can be examined further through splitting the mixed-mode into natural and mechanical.

As noted before, the use of attainment to directly compare schools can lead to misleading conclusions, as such when comparing schools within one year, this study has weighted the school performance using the deprivation index, reducing the influence of the school background. This has been compared using a MANOVA comparison, identifying whether there is any significant difference between any of the internal environments (Field and Miles 2010, chap. 16). Furthering this examination of the building specific variables, the BREEAM (BRE Environmental Assessment Method) rating was evaluated to determine whether there was any significant difference between those that achieved BREEAM "Very Good" or better and those that did not using an independent t-test (Field and Miles 2010). BREEAM ratings indicate the environmental performance of the building against a set of criteria determined by the BRE (BRE, 2013). There are a number of different ratings, from "Pass", "Good", Very Good", "Excellent", up to "Outstanding", representing their relative performance against the criteria. It should be noted that the BREEAM rating system purely looks at the sustainability of the building and not the educational vision of the school, but Leaman and Bordass in their work noted that users, overall, seem to be more tolerant of 'green' buildings (Leaman & Bordass, 2007), and this may have a similar impact on school performance. Within their work, Leaman and Bordass note that despite the overall tendency for greater satisfaction within greener buildings, it is also directly reliant on the internal environments created within the buildings, with green buildings found to have noticeably better air quality. Should schools with a better BREEAM rating be found to have significantly improved results, then it may be indicative that these schools have correspondingly better environments as a consequence of the demands of the BREEAM system. This raises the question that should a significant difference be found between the BREEAM ratings then this may be indicative that the schools have that perform better have correspondingly better internal environment performance.

# 4 Results: Development and Analysis of the Unified School Database

Within this section the results from the analysis of the unified school database are presented. There are four main sections of results, the first looking at the energy performance, and then next three looking at attainment within the new schools.

## 4.1 Energy performance of schools

The energy performance of new and old buildings has been explored to understand the performance of the new school buildings. The first part of this research looks into the relationship between the deprivation-weighted attainment and the energy usage. The second part looks at the energy performance of the BSF schools compared to the existing schools to see if there is a significant difference in performance.

### 4.1.1 Energy Performance of BSF Schools

The new BSF buildings have been compared to the existing building stock for the academic year 2011-12, shown in Figure 4.1. This breaks down the energy use by electricity, heating (natural gas), and total energy use. From Figure 4.1 it is clear that the new schools are using significantly more electricity than the existing building stock ($t(75)=4.917$, $p<0.001$), the heating is significantly less ($t(75)=3.416$, $p<0.001$) and overall there is no significant difference in energy use ($t(75)=1.032$, $p=0.153$). Given the improvement in building fabric mandated by Part L2A of the building regulations[15], the reduction in heating energy is expected, but the increase in electricity use suggests the improving building technology is not reducing electricity usage. This echoes the findings of Bruhn et al (2011) and Godoy-Shimzu et al. (2011), when comparing school energy use to the CIBSE benchmarks (CIBSE 2008), suggesting that there may be a national change in school energy usage in parallel with the new building. One potential reason is the increase in ICT, a focus within the BSF process (Mahony, Hextall, and Richardson 2011), which draws more electricity and passively heats many of the spaces the equipment is within.

[15] Up to date and historical versions of Part L2A are available from here: https://www.gov.uk/government/publications/conservation-of-fuel-and-power-approved-document-l (last accessed 02/07/2016).

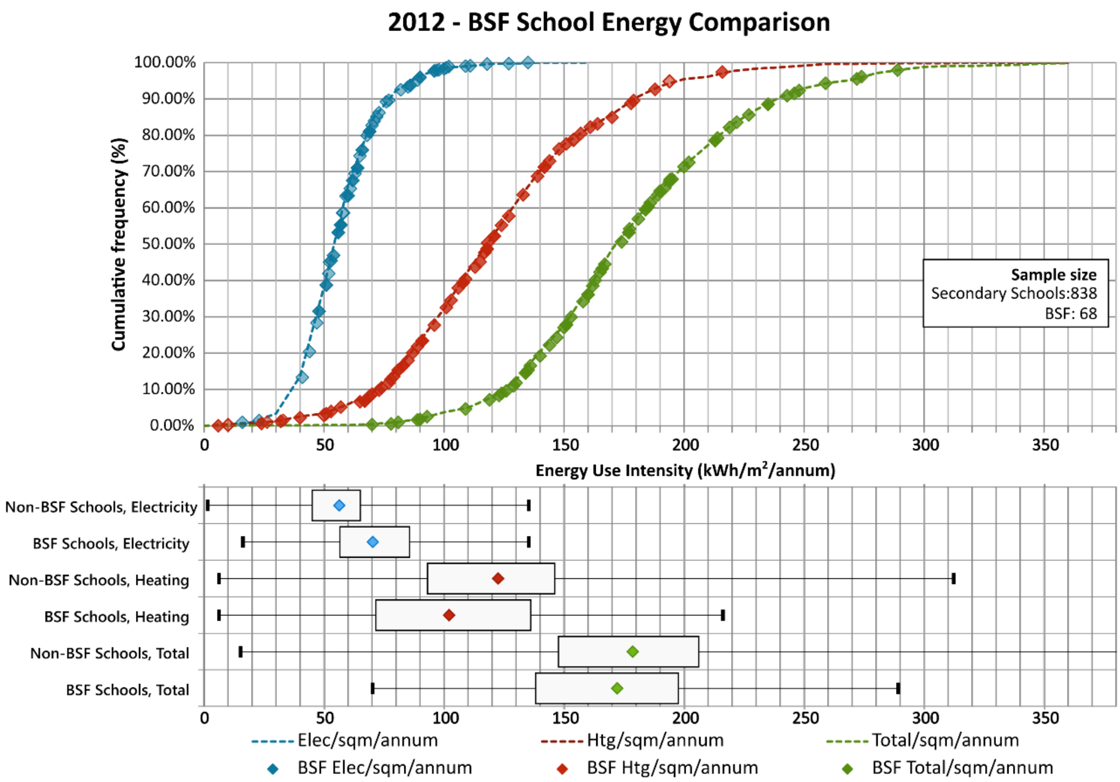



**Figure 4.1 – Cumulative frequency graph (top) showing the BSF school energy performance as part of the school building stock, and a box and whisker plot (bottom) comparing the distribution of energy usage for BSF and non-BSF schools**

### 4.1.2 Energy and Academic Performance

Many of the regression analyses in Table 4.1 demonstrate that the deprivation-weighted school performance metrics had a small but significant relationship with the energy consumption of the school, taken as those with a Pr>F value less than 0.01, showing that schools that perform better tend to have higher energy consumption (both heating and electricity). Despite the significance, the greatest variance explained by the deprivation weighted attainment is 1.59%, shown in Figure 4.2, between Level 1 performance and heating energy use. For both electricity and heating per square meter, the percentage of students achieving level 1 at their GCSE exams (5 or more GCSEs at A*-G) was a better predictor of energy use than the other performance metrics.

The correlation between the amount of energy consumed and the school performance improves when the energy is pupil centred rather than area-weighted, as shown in Table 4.2 below. This reinforces the concept that schools that perform better use more energy when using area-weighted energy metrics, with improvements in Level 1 results accounting for 11.5% of the overall energy use (Figure 4.3). As with the findings of Godoy-Shimzu et al. (2011), the energy use in buildings relates closely to the occupant centred energy metrics rather than area-weighted metrics.

**Table 4.1 – Results of regression between the deprivation-weighted performance indices and the energy consumption**

| Deprivation weighted performance indicator | Electricity per m² (kWh/m2/annum) | | | Heating per m² (weather corrected, kWh/m²/annum) | | |
|---|---|---|---|---|---|---|
| | F Value | Pr>F | $R^2$ | F Value | Pr>F | $R^2$ |
| % Achieving Level 2 inc. English and Maths | 6.93 | 0.0086 | 0.0081 | 1.91 | 0.167 | 0.0023 |
| % Achieving Level 2 | 7.34 | 0.0069 | 0.0086 | 12.75 | 0.0004 | 0.015 |
| % Achieving Level 1 | 12.23 | 0.0005 | 0.0143 | 13.48 | 0.0003 | 0.0159 |
| % of students persistently absent | 0.32 | 0.574 | 0.0004 | 8.72 | 0.0032 | 0.0104 |
| % of half days missed | 1.26 | 0.2613 | 0.0015 | 10.48 | 0.0013 | 0.0126 |

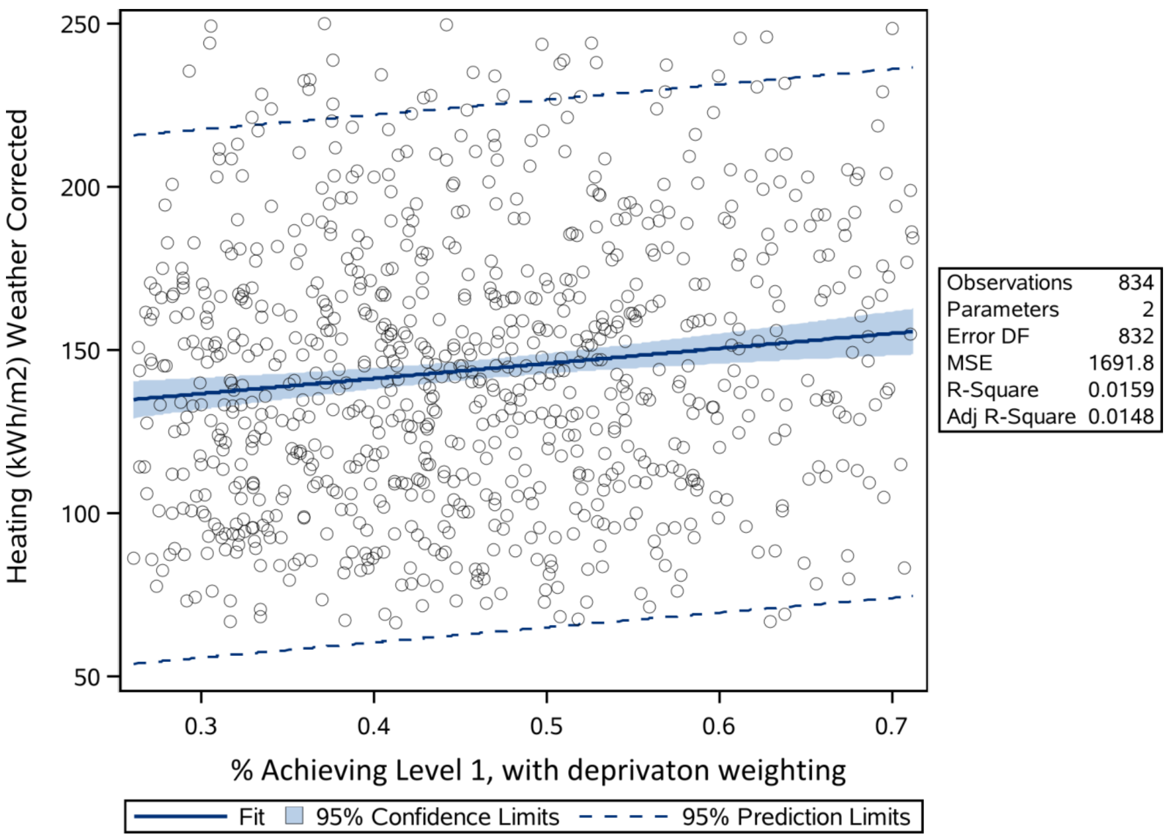



**Figure 4.2 – Regression analysis between the deprivation-weighted level 1 results and the weather-corrected heating energy consumption per m² per annum**

**Table 4.2 – Results of regression analysis between the energy use per pupil and the deprivation-weighted school performance**

| Deprivation weighted performance indicator | Electricity per pupil (kWh/pupil/annum) | | | Heating per pupil (weather corrected, kWh/pupil/annum) | | |
|---|---|---|---|---|---|---|
| | F Value | Pr>F | $R^2$ | F Value | Pr>F | $R^2$ |
| % Achieving Level 2 inc. English and Maths | 0.20 | 0.6534 | 0.0002 | 0.36 | 0.5512 | 0.0004 |
| % Achieving Level 2 | 36.82 | <.0001 | 0.0425 | 26.22 | <.0001 | 0.0308 |
| % Achieving Level 1 | 107.09 | <.0001 | 0.1150 | 60.87 | <.0001 | 0.0690 |
| % of students persistently absent | 92.59 | <.0001 | 0.1008 | 61.65 | <.0001 | 0.0699 |
| % of half days missed | 95.22 | <.0001 | 0.1039 | 54.78 | <.0001 | 0.0631 |

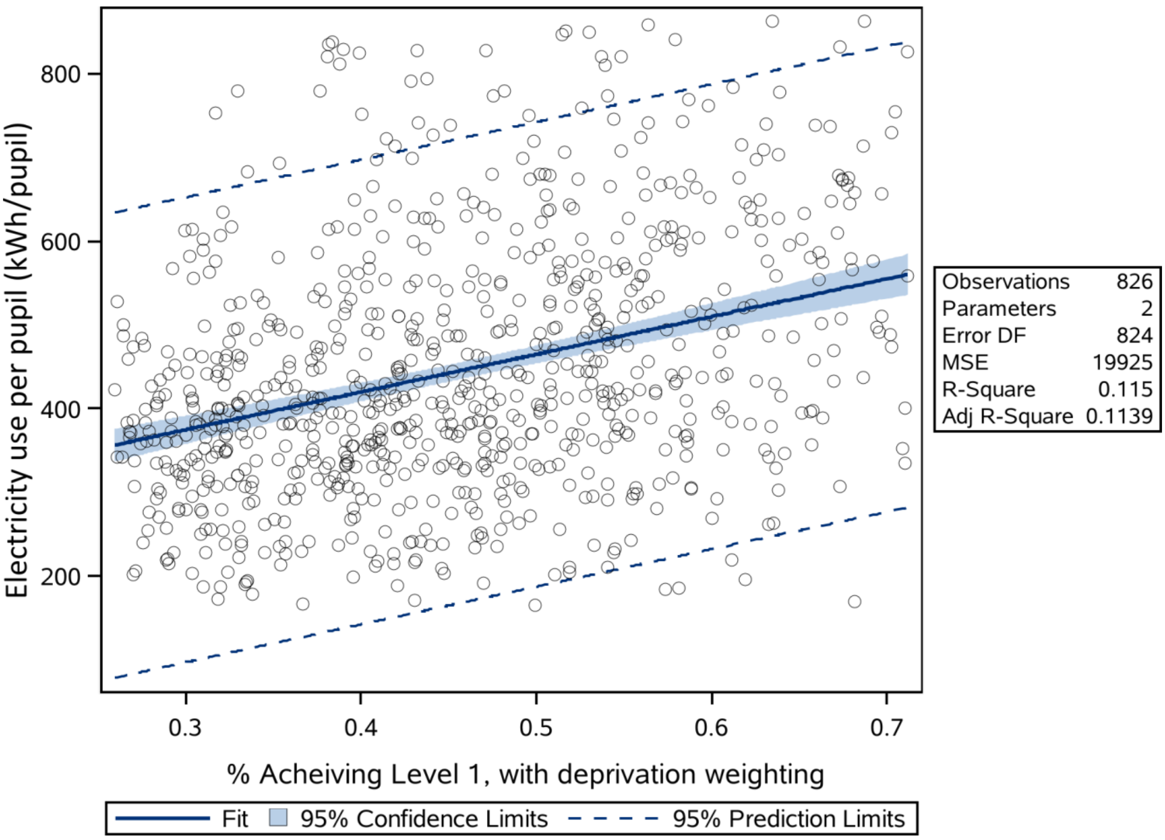



**Figure 4.3 – Graph showing the relationship between the deprivation weighted level 1 performance and the electricity usage per pupil**

## 4.2 Influence of the changing school environment

As discussed in section 3.3.2, one method to explore the changing school performance is to explore the transition of the school through 4 different states:

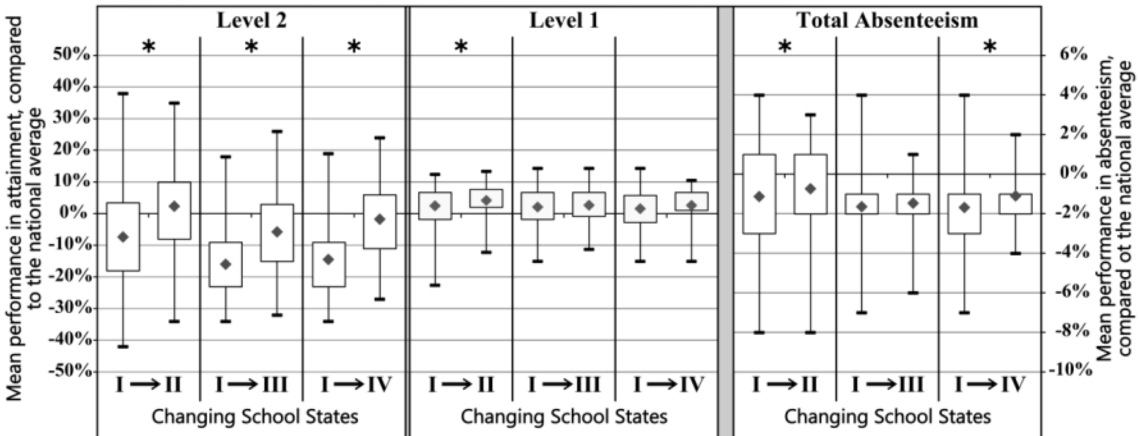
I. The initial state (taken as the earliest record of the school during the study period)

II. The original school type and a new school building (with the school type referring to community, voluntary aided/controlled, academy or specialist college)

III. Change in school type but original school building

IV. Change in school type and new school building

Evaluating the movement of the school through these four states finds that significant changes do occur to the school performance, with the differing metrics used indicating differing levels of performance change, illustrated in Figure 4.4. When using mean normalised Level 2 performance as a metric, the change to each state shows significant improvement ($p<0.001$), with a change in school type and school building showing the largest improvement (state I to state IV mean change of 12.69%), and the move to the new building showing the lowest amount of improvement (state I to state II mean change of 7.20%). A similar relationship is repeated using the total absenteeism, with changing school type and building showing the largest improvement (state I to state IV mean change of 0.59%), and changing only the school building showing a modest improvement (state I to state II mean change of 0.40%). However, no significant improvement was noticeable when changing only the school type using total absenteeism as a metric. The mean normalised Level 1 metric shows the least significance, with only the move to the new building (state II) showing statistical significance (mean change of 1.77%).



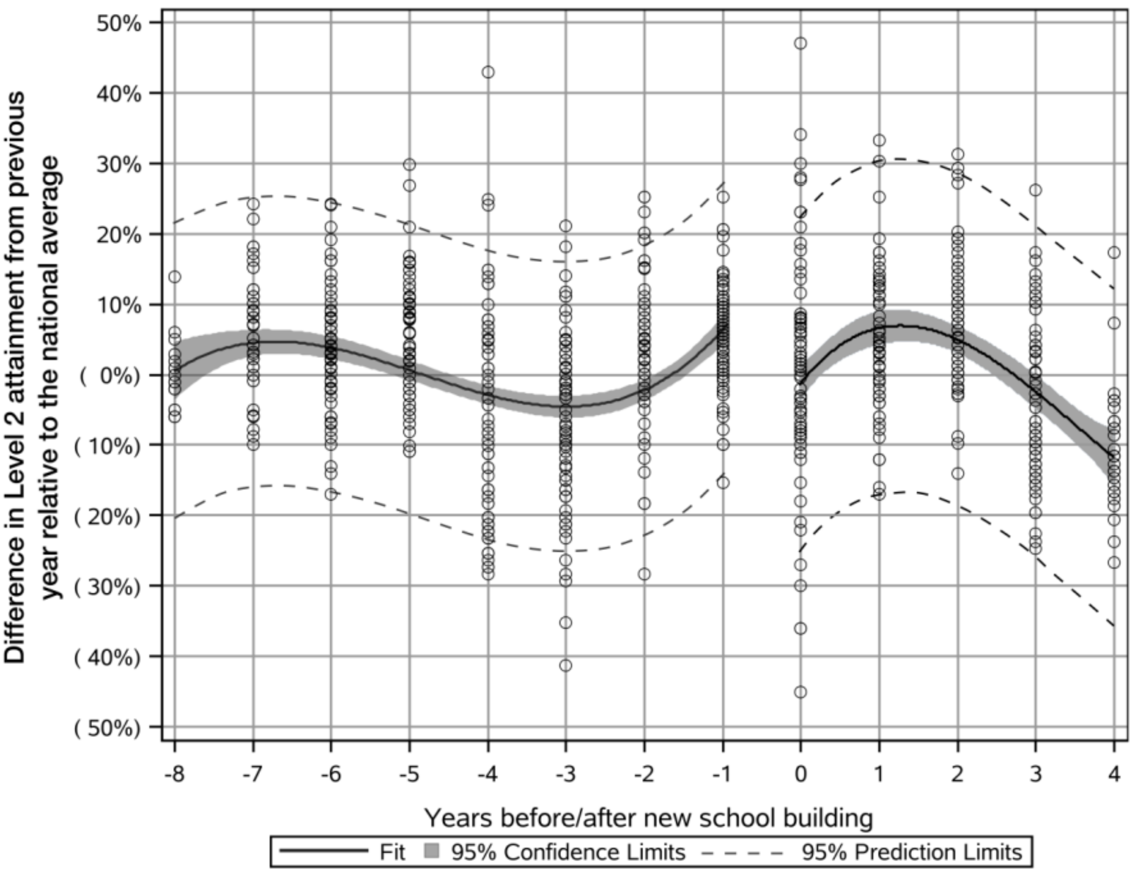

| | Level 2 I→II | Level 2 I→III | Level 2 I→IV | Level 1 I→II | Level 1 I→III | Level 1 I→IV | Total Absenteeism I→II | Total Absenteeism I→III | Total Absenteeism I→IV |
|---|---|---|---|---|---|---|---|---|---|
| N | 248 | 72 | 74 | 236 | 67 | 70 | 258 | 75 | 79 |
| Mean Before | -7.00% | -15.90% | -14.77% | 2.54% | 2.10% | 1.57% | -1.10% | -1.60% | -1.69% |
| Mean After | 2.24% | -5.46% | -2.56% | 4.31% | 2.73% | 2.66% | -0.70% | -1.50% | -1.10% |
| Signed Rank, S | 10791 | 1080 | 1345.5 | 3804.5 | 103.5 | 165 | 2013 | 26 | 337 |
| P | <.0001 | <.0001 | <.0001 | <.0001 | 0.4616 | 0.2617 | 0.0014 | 0.8020 | 0.088 |

**Figure 4.4 – Graph showing the difference in school performance when the school changes state, with those showing significance indicated with a * above**

## 4.3 Performance before and after the new building

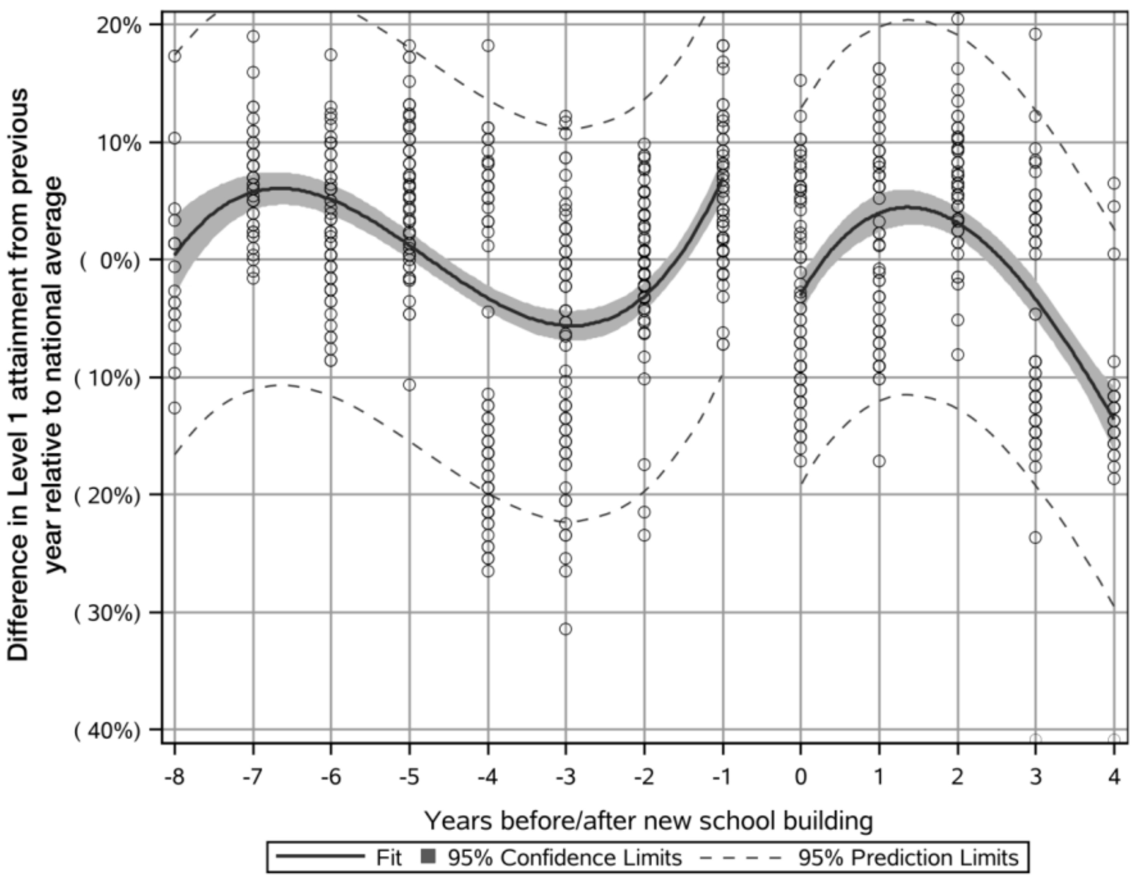
The means used in preceding section describe the changes in the school performance in a straightforward before/after manner, but this does illustrate the process these schools take to achieve these changes. By plotting the year-on-year performance of the schools against the number of years before and after the new building, this route can be more clearly seen and analysed using a regression discontinuity analysis. The results are shown in Figure 4.5, Figure 4.6, and Figure 4.7.

The regression discontinuity analysis was undertaken only for schools that had results for the third year after opening and at least six years before, ensuring that there was sufficient data for the analysis (N=75) and extending the Rintala and Griggs study (Rintala & Griggs, 2009). For both the Level 2 and Level 1 analysis (see Figure 4.5 and Figure 4.6), prior to the new building, the regression line representing results is a third order equation, whereas after the new building the regression line is a second order equation, illustrating a significant change in behaviour since the move to the new school building. A similar trend is visible when examining the total absenteeism (see Figure 4.7); but with no significant trend observable following the move to the new building.




| | BEFORE | | | | AFTER | | | |
|---|---|---|---|---|---|---|---|---|
| Parameter | Estimate | Std. Err. | t Value | Pr > \|t\| | Estimate | Std. Err. | t Value | Pr > \|t\| |
| Intercept | 0.256 | 0.032 | 8.11 | <.0001 | -0.012 | 0.013 | -0.93 | 0.355 |
| x | 0.229 | 0.030 | 7.72 | <.0001 | 0.140 | 0.035 | 4.06 | <.0001 |
| $x^2$ | 0.055 | 0.008 | 7.04 | <.0001 | -0.067 | 0.022 | -2.95 | 0.0034 |
| $x^3$ | 0.004 | 0.001 | 6.24 | <.0001 | 0.006 | 0.004 | 1.64 | 0.1027 |

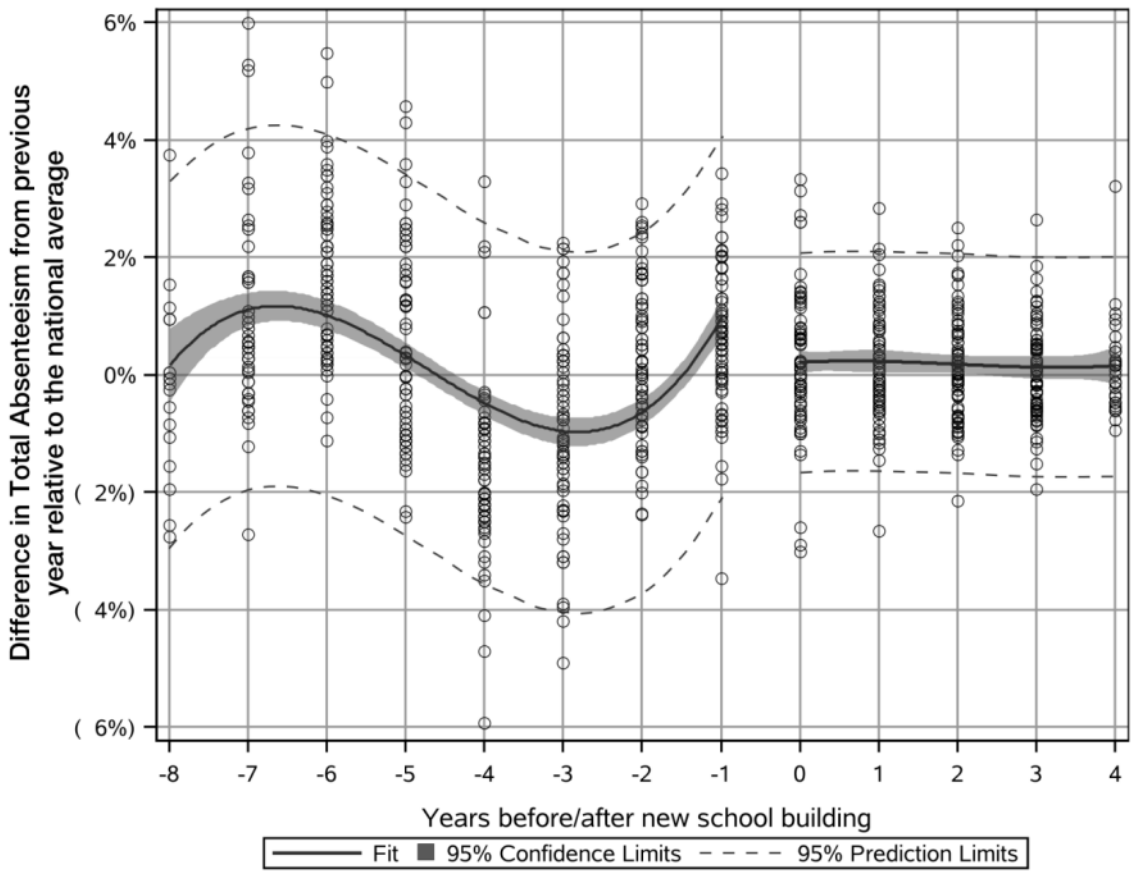
**Figure 4.5 – Regression discontinuity analysis showing the difference between in the level 2 performance before and after the new building**




| | BEFORE | | | | AFTER | | | |
|---|---|---|---|---|---|---|---|---|
| Parameter | Estimate | Std. Err. | t Value | Pr > \|t\| | Estimate | Std. Err. | t Value | Pr > \|t\| |
| Intercept | 0.273 | 0.025 | 10.77 | <.0001 | -0.028 | 0.008 | -3.13 | 0.0019 |
| x | 0.263 | 0.024 | 11.04 | <.0001 | 0.114 | 0.023 | 4.94 | <.0001 |
| $x^2$ | 0.065 | 0.006 | 10.35 | <.0001 | -0.048 | 0.015 | -3.21 | 0.0015 |
| $x^3$ | 0.004 | 0.000 | 9.32 | <.0001 | 0.003 | 0.003 | 1.30 | 0.1929 |

**Figure 4.6 – Regression discontinuity analysis showing the difference between in the level 1 performance before and after the new building**

Clearly noticeable from all three regression-discontinuity analyses is that the schools tend to improve two years prior to the move to the new building, following a period of decline. This improvement trend continues in the attainment metrics, with a slight drop in year zero, followed by a significant drop following year two. The prior improvement cannot be attributed to new building, indeed it would be expected that during this period the disruption of constructing the new school would hinder the performance of the schools (particularly through the additional noise that has a well understood effect on the learning environment (Shield & Dockrell, 2003)). In most cases, the school performance had declined prior to the improvement, suggesting that those schools targeted by the BSF programme were underperforming, and as such would have been ideal candidates to receive the new building.




| | BEFORE | | | | AFTER | | | |
|---|---|---|---|---|---|---|---|---|
| Parameter | Estimate | Std. Err. | t Value | Pr > \|t\| | Estimate | Std. Err. | t Value | Pr > \|t\| |
| Intercept | 0.044 | 0.005 | 9.37 | <.0001 | 0.002 | 0.001 | 1.48 | 0.1385 |
| x | 0.044 | 0.004 | 9.95 | <.0001 | 0.001 | 0.003 | 0.29 | 0.773 |
| $x^2$ | 0.011 | 0.001 | 9.53 | <.0001 | -0.001 | 0.002 | -0.4 | 0.6897 |
| $x^3$ | 0.001 | 0.000 | 8.67 | <.0001 | 0.000 | 0.000 | 0.4 | 0.6915 |

**Figure 4.7 – Regression discontinuity analysis showing the difference between in the total absenteeism before and after the new building,**

There is a clear influence from the act of building a new school under the BSF programme, with much of the improvement occurring prior to the new building being constructed. At the end of the BSF programme in June 2010, there were 715 schools that had their funding for a new school cut (The Guardian, 2010). Using this dataset, the cumulative Level 2 performance was examined, shown in Figure 4.8, with a sharp increase in the performance prior to the cancellation that continues on for one year, before the results drop by 12.5% on average. This highlights the impact that expecting a new school can have on the school climate without a physical change in the environment. It also shows the influence of government policy on the school performance, with the good-will built up through the BSF process quickly reduced.

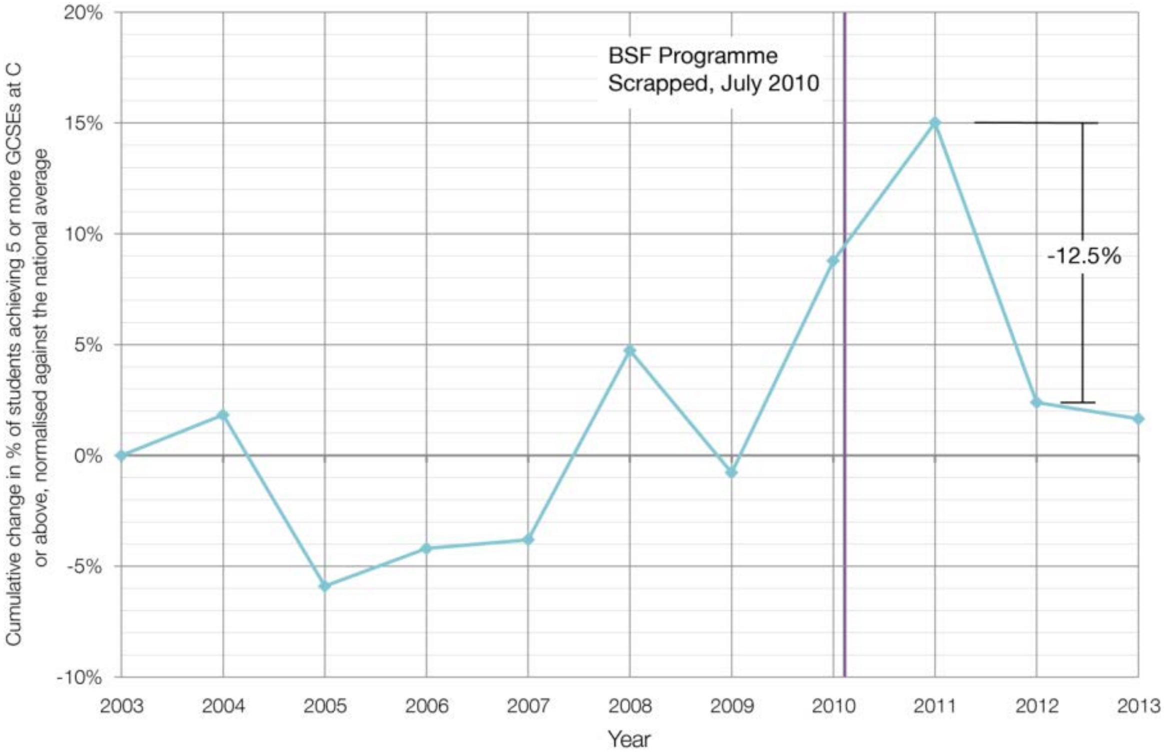



**Figure 4.8 – Cumulative average percentage of students achieving 5 or more GCSEs at grade C or more in the schools that had their BSF schools scrapped in July 2010, based on a sub-set of 310 schools**

### 4.4 Internal environment

The learning environments provided follow many different educational visions, with these visions interpreted by the design teams in various manners. However, through the DECs for the completed schools, the internal environment can be examined for trends in heating and ventilation systems, understanding whether one internal environment[16] has been more successful for the overall learning environment than the others. As noted before, the use of attainment to compare schools can result in misleading conclusions; as such this study has used the deprivation weighted attainment to directly compare the schools within one year. Conducting a MANOVA comparison (Field and Miles 2010) to identify significant differences between the school internal environments showed no significant difference in deprivation weighted performance for either Level 2 or Level 1 attainment (see Table 4.3) in any of the years available

[16] Note the internal environments tested were: air conditioning, heating and mechanical ventilation, heating and natural ventilation, and mixed mode. These were taken from the DEC data available from 2007-8 onwards.

**Table 4.3 – Results from the MANOVA exploring the differing internal environments and school performance, for each year and the school performance metric.**

| *Metric* | *Year* | *N* | *F* | *PR>F* |
|---|---|---|---|---|
| Deprivation weighted level 2 | 2011-12 | 71 | 0.16 | 0.9257 |
| | 2010-11 | 62 | 1.27 | 0.2895 |
| | 2008-09 | 96 | 2.01 | 0.1181 |
| | 2007-08 | 82 | 0.55 | 0.5775 |
| Deprivation weighted level 1 | 2011-12 | 71 | 0.54 | 0.6561 |
| | 2010-11 | 62 | 0.62 | 0.5403 |
| | 2008-09 | 96 | 0.92 | 0.4357 |
| | 2007-08 | 82 | 0.57 | 0.5677 |

Further investigating the direct link between the building and the performance, the relative performance of buildings BREEAM rated “Very Good” or better, compared to those with no rating has been examined. Focusing on academic year 2011-12, as it contains the highest number of new schools, an independent t-test was undertaken that looks for significant change between two independent groups. No significant difference found between those achieving “Very Good” (Mean = 0.491, Standard Error = 0.017) and those not achieving this rating (Mean = 0.500, Standard Error = 0.010), $t(264) = -0.490$, $p = 0.624$, $r = 0.045$, when examining the deprivation-weighted Level 2 results. Similarly, when examining the deprivation-weighted Level 1 results, those achieving “Very Good” (Mean = 0.251, Standard Error = 0.008) were not significantly different from those not achieving a rating (M = 0.258, SE = 0.005), $t(261) = -0.790$, $p = 0.434$, $r = 0.065$. The high p-values for both Level 2 and Level 1 indicates that although schools have high BREEAM ratings, there is no statistical link to the school attainment.

## 4.5 Summary

Within these results, there has been a national-level analysis of school performance enabled through the creation of the unified school database. The importance of a new building has been explored both from an energy and academic performance point-of-view. This found that the new building had a measurable effect on the school performance.

*Moving to a new school building and changing the type of school results in the greatest improvement in attainment.*

Examining the changes between the states, it is apparent that building a new school and changing the school type (predominantly the change to an academy) will yield the largest improvement in performance, both in absenteeism and attainment. It is also clear that moving to a new school building will also significantly increase school attainment and reduce absenteeism (though not as much as when coupled with a change in type) and changing only the school type will improve the attainment, but not necessarily the absenteeism.

*The act of creating a new building improves the school attainment.*

From the longitudinal analysis of the BSF schools, a pattern of attainment and absenteeism that improves prior to the move into the new building. This same pattern is clear even in those schools promised a new school under BSF, but did not receive one. It is clear that this improvement does not occur as a result of the new building, in fact it occurs despite the additional disruption of managing delivery of a new school and any associated building works on close to the school. It suggests that the BSF programme acts as a catalyst for a change to the school that has a consequential improvements.

*The improvement arising from a new building is not necessarily sustainable.*

As the GCSE programme is a two-year programme, the results in year two and onwards represent those taught at GCSE level entirely in the new building, with results prior to this year partially influenced by the old building and the disruption of the move. Following year two, the attainment results decline sharply, with the progression not just slowing, but actually reversing for many of the schools, ending five years of improvement. This is especially clear in Figure 4.8, examining those schools that were denied the BSF school they were promised. The improvement in attainment arises without the new building being constructed, but without that promise of a new building, the cumulative improvement disappears at rate quicker than any of the preceding improvement.

*Total absenteeism rate is not an indicator of school performance at a national level*

The total absenteeism rate follows no significant regression line following the move to the new building, with the average just above zero (mean = 0.13%, note that positive figures denote reduced absenteeism). While it is not possible to say that the new building has reduced absenteeism, the improvement before the new building has not deteriorated in the same manner seen in attainment. This strengthens the notion that the building is not the main driver behind improvement in schools, but rather something that happens as part of the run-up to the new building is actually driving the change, and the building itself is an enabler.

*The generic measures of building environment do not have a link with school performance.*

Both the BREEAM ratings and the internal environment are high-level measures of the constructed environment, but do not measure the actual environment they create. As such, it only highlights the difficulty of assessing the school performance from simple, building metrics. Methodologically, there are complications using the deprivation–weighted attainment, as not all the school context is captured, but the lack of significant findings may indicate that the new buildings meet the minimum requirements, regardless of the designs used. As such, these criteria may be 'satisficers', where as long as the minimum is met, no deterioration of performance would be expected, as discussed by Woolner et al (2007). Alternatively, the aspects measured may have such a limited impact that other factors simply hide any relationships. This may account for the dip in attainment in year 3 following the move to the new building, where a change to the school that has not been captured in this study has resulted in a significant drop in performance.

*Overall energy performance is not significantly different in new buildings, but is weakly linked to the school performance.*

Evaluating the energy performance of schools compared to the deprivation-weighted performance of each school, found that those schools performing better (notably in Level 1 attainment) used significantly more energy (up to 11.5% more energy per pupil using the Level 1 attainment). The influence in Level 1 performance rather than Level 2 may indicate that additional work is needed to help students in schools where attainment is low, as Level 1 is a lower level of performance than Level 2. It was also found that the new BSF schools used significantly more electricity than the existing school building stock (70.0 kWh/m$^2$/annum compared to 56.1 kWh/m$^2$/annum), but significantly less heating (101.9 kWh/m$^2$/annum compared to 122.2 kWh/m$^2$/annum), with no significant difference in overall energy usage.

# 5 Selection of Case Study Schools for School Level Analysis

The high-level study outlined in chapters 3 and 4 showed that there are tangible effects of a school operating in a new building, but the direct influence of the building is not apparent from the limited datasets. To capture the impact of the built environment requires a low-level, school analysis, capturing the whole school and analysing the interplay of the various components. With over 3,500 schools in England (DfE, n.d.-a) it is not practical to measure each school, instead a case study approach has been taken, using four schools to illustrate the new building in England. Within this chapter, the selected schools are introduced.

## 5.1 School Selection Criteria

Building on the national-level work from the previous chapters, secondary schools were chosen as the focus within the case-study analysis. Similarly, it was decided to reflect on the most recently built schools, whether built under the BSF programme or through similar government initiatives. As discussed in chapter 2, there are other periods of school design, but perhaps the best opportunity to improve future designs is to explore the most recent designs, with the strong guidance and governance providing a minimum set of design criteria that may not have existed in previous school building periods. Additionally, by reflecting on recently constructed schools, the relevance to future school design is increased as the construction techniques and materials are far more likely to be still used. For example, finding that single-glazing is thermally inefficient would not be particularly useful to future designs.

Using the unified school database from chapters 3 and 4, the schools designed by Feilden Clegg Bradley Studios architects (FCBS) were analysed. Given that the BSF schools struggle to keep up the momentum of improvement after the move to the new school, the cumulative performance of the BSF schools has been used to determine whether at the end of the measured period the schools have progressed from the start of this study to enable the analysis of FCBS schools. Focusing on the Level 2 attainment, Figure 5.1 shows the overall BSF school mean, with the clear dip in year 4 returning the school to the original attainment performance characteristics. For comparison, the schools produced by Feilden Clegg Bradley Studios (FCBS) have been overlaid on to this cumulative performance, showing that all but one outperforms the BSF schools. These FCBS are not BSF schools and many do not have data available for the whole period, so the results should be treated with caution, but it does indicate the grouping of schools that may exist within the BSF schools. This above average performance of the Feilden Clegg Bradley Studios' schools suggests that there is a potential differentiator that warrants further analysis. As such, the case study schools will be chosen from their buildings. Within one architectural practice, the approach to the client brief and building regulations can be assumed to relatively constant, particularly if, as in the case of the buildings chosen, the design team remains similar. Additionally, the research can build on the existing relationship of the design team, enabling access to schools that would otherwise not be inclined to be involved.

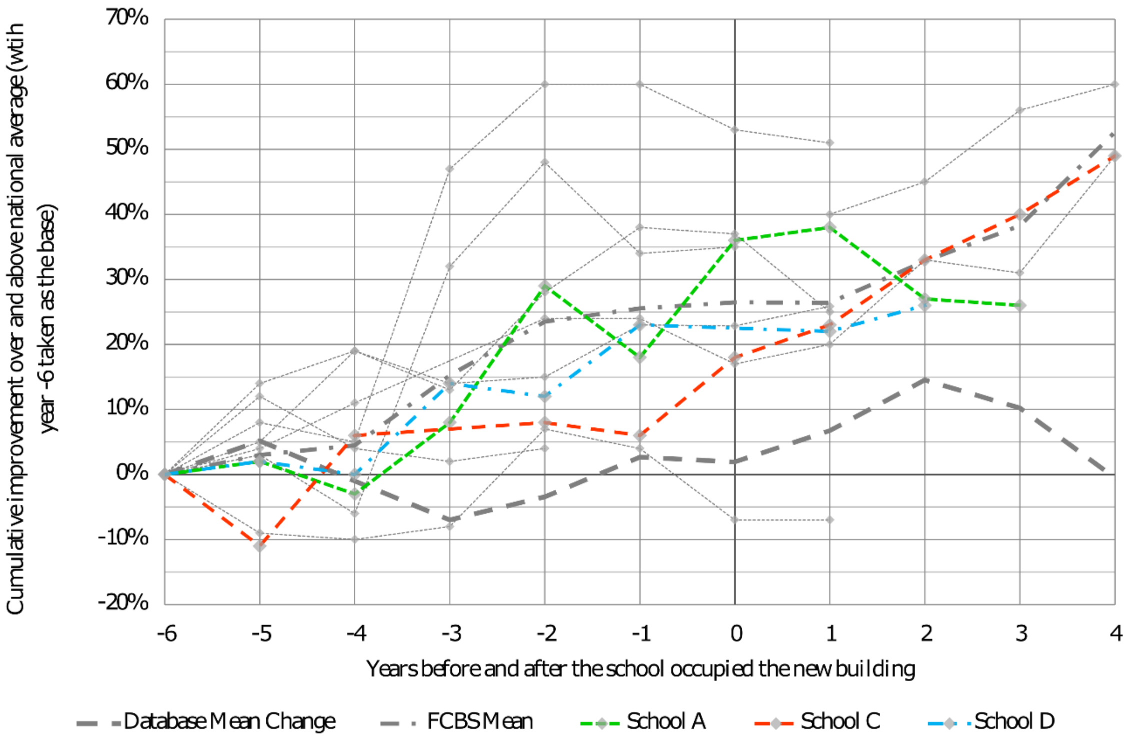



**Figure 5.1 – Cumulative level 2 attainment of the case study schools compared to the BSF schools. Note School B did not have any level 2 data available at the time of the study.**

To ensure robustness of the data collected, a number of additional practical conditions were set:

- Minimum student age of 11
- School occupied the new building for at least two years
- School type (academy or otherwise) unchanged for at least two years
- Accessible
- Available layout plans
- Access to the students and staff

- Access to the teaching and communal spaces during use
- Designed by Feilden Clegg Bradley Studios (FCBS)

The requirement for each school to have a minimum age of 11 is to ensure that the students in each school have experienced the same education structure, with the move from primary school to secondary school forming an important developmental step (Zeedyk et al., 2003). These conditions extend to 'through' schools, where the primary school is on the same site as the secondary school. The increased familiarity of the students to the building is rare in the secondary school system in the England and could unduly skew the results of this study.

Ensuring that the school has been occupied by the school for at least two years is required to reduce the teething problems found in new buildings. This is a recognised issue, with the defects period in any construction project existing to address these initial problems and the underlying causes arising due to a number of different factors (Josephson found 7 underlying origins for defects (Josephson & Hammarlund, 1999)). While there is no definite cut-off point for the end of the defects, two years allows time to overcome any initial construction issues and the school to adapt.

Similar to the need to remove the influence of the construction process by ensuring at least two years of occupation of the current building, it was decided to ensure the schools selected had not changed type (e.g.: to an academy) for at least two years prior to the study. The change in school type is not necessarily disruptive, but anecdotally the change to an academy has been disruptive in a number of schools. One of the schools studied found a number of senior teaching staff left following the change to academy status. This is reinforced by the National Union of Teachers (NUT) which disapproves of academies over state education (NUT, n.d.) and encourages the staff to protect state schools. While no research points to the exact the time period for this transition to 'settle down', through discussion with teachers and schools, it was felt that two years provided enough time to rehire any staff that may have left and to enact any of the changes to the school that were planned.

Perhaps the most important aspect of the study schools is their accessibility, including the design information as well as access to the school and occupants. Ensuring that the school is prepared to grant access to the building during operational hours and to the students takes precedent over all other aspects. The broad nature of this study requires considerable access to the school, despite the efforts to reduce the burden on the school, and this access was discussed at length with each potential school to ensure their acceptance of the research methods.

Building on the influence of the design and the architectural practice, the schools have been selected to reflect the differing typologies set out in Feilden Clegg Bradley Studios' *Places for Learning* book (Feilden Clegg Bradley Studios, 2009). This sets out five typologies for modern schools (shown in Figure 5.2), with the most appropriate typology adapted for the client brief and site constraints. The interplay of the typology and the school climate will provide an additional dimension to the aspects monitored, with the typology potentially affecting the connectedness of the spaces and the management of the spaces.

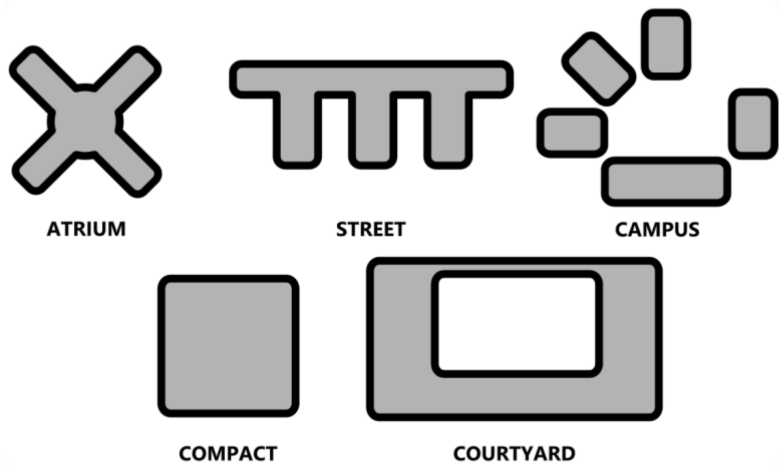



**Figure 5.2 – Indicative diagrams showing the school typologies outlined by FCBS**

Each typology described in *Places for Learning* has its own distinctive properties that separate it from the other typologies:

**Atrium**: A school that is formed around a central atrium or heart space

**Street**: A grand circulation route with teaching wings built off this central spine

**Campus**: A collection of buildings sharing a site, potentially connected by covered walkways

**Compact**: School built with tight site constraints forcing a taller building, with roof top spaces

**Courtyard**: The school is formed to create a central, secure courtyard, forming a part of the circulation

## 5.2 School Backgrounds

In all, four schools were chosen, with five schools initially targeted to match each typology, but the fifth school was not able to participate due to time commitments. Each school is summarised in Table 5.1, showing the background to the building and the school. The four schools represent a mix of locations, occupant densities, building typologies, ventilation systems and ages. Layouts of the schools are shown in Appendix B.

**Table 5.1 – Details of the four schools studied in the bottom-up approach**

| | School A | School B | School C | School D |
|---|---|---|---|---|
| ***Location*** | Kent | Central London | Northamptonshire | Sussex |
| ***Setting*** | Suburban | Urban | Suburban | Rural |
| ***Construction Date*** | 2010 | 2009 | 2006 | 2011 |
| ***Type*** | State school | Academy, Sponsor Led | Academy, Sponsor Led | Academy, Sponsor Led |
| ***Typology*** | Atrium | Compact | Courtyard | Street |
| ***Gross Internal Floor Area (GIFA)*** | 8,257 $m^2$ | 10,960 $m^2$ | 11,921 $m^2$ | 11,660 $m^2$ |
| ***Number of full-time equivalent pupils (as of September 2014)*** | 724 | 840 | 1376 | 618 |
| ***Number of Storeys*** | 3 | 6 | 2 | 2 |
| ***Pupil density*** | 11.25 $m^2$/pupil | 13.05 $m^2$/pupil | 8.66 $m^2$/pupil | 18.87 $m^2$/pupil |
| ***% of pupils eligible for free school meals*** | 24.8% | 30.9% | 27.6% | 41.8% |
| ***% of pupils with SEN statement or on School Action Plus*** | 16.8% | 7.3% | 5.3% | 18.4% |
| ***Gender*** | Mixed | Mixed | Mixed | Mixed |
| ***% of boys on roll*** | 50.1% | 58.1% | 53.6% | 48.5% |
| ***Age Range*** | 11-16 | 11-18 | 11-18 | 11-18 |
| ***Heating system*** | Gas fired boiler with perimeter radiators | Ground source heat pump with perimeter radiators | Gas fired boiler with perimeter radiators and underfloor heating in admin rooms | Gas fired boilers with underfloor heating. |
| ***Ventilation system*** | Natural ventilation through opening windows | Mixed mode; mechanical ventilation with openable windows | Mixed mode; mechanical ventilation with openable windows | Mixed mode; mechanical ventilation with actuated windows and wind-catcher style roof units. |

School A is located on the edge of the suburbs, with the eastern side exposed to farmland. The school is centred around a two-storey atrium, with four main teaching wings plus a larger fifth teaching wing that houses the sports hall, dining area, dance studio, home economics suite and staff offices. Each of the four main teaching wings is dedicated to a specific teaching discipline (maths for example), with a mix of 'traditional' cellular teaching spaces and an open plan teaching area on both floor (note that the third floor is for the art studio only). These open plan teaching areas effectively operate as two or three teaching rooms without walls, with furniture and screens used to split up the spaces.

The city-centre location of school B necessitates the increased number of floors to accommodate the number of students on tight site. Following the heights of nearby buildings, the school is staggered with north end of the school two stories above ground level, and the southern end five stories above ground level. Within the basement are the sports halls, drama studio and main school hall, while the entrance lobby on the ground floor links directly to the open plan dining area. To get daylight within the deep plan building, three large atria are included along the spine of the building, bringing light down to the ground floor 'street'. On the upper floors, narrow circulation winds around the atria, classrooms and rooftop spaces, necessitating the use of a one-way system to reduce overcrowding. Teaching spaces are all typical classrooms, with glazing down either one or two sides of the room.

The oldest of the four schools is school C, with a suburban location close to a dual carriageway. The form of the building is built around a large central courtyard that forms part of the circulation as well as space for the students during breaks. Four teaching wings radiate from the central courtyard, each two stories tall, with the north-west corner of the courtyard a larger zone consisting of a sports hall, dining area, library and sixth form area. Each of the teaching wings is connected by a corridor at first floor level only, with access to the ground floor via an atrium in each wing or via the courtyard. As with school B, teaching spaces are traditional cellular types, although all internal walls have been made non-structural to enable simple relocation to form new teaching spaces.

School D is in a rural setting, although it is close to a local railway line and a dual carriageway, placed midway up a hill overlooking a valley. The school is formed around a wide central circulation spine with teaching wings on the south-east side, away from the railway line and dual carriageway. At the southern end of the circulation spine is the main hall and dining area, with the sports hall and drama spaces at the other end. Teaching spaces are similar to those within schools B and C, with traditional cellular type rooms. On the ground floor of one of the teaching wings, the open plan area designed for year 7 students, has been temporarily taken over by a bilingual, primary free school until their new school building is finished.

Schools B and D are not at full capacity as yet, with school B a new school to the area and school D expanding from its previous iteration, notably a larger sixth form provision. While school D is not at capacity, a self-contained free school has been integrated into the building, taking over one floor of a teaching wing. This free school is entirely separate from the academy in the rest of the building, with no movement between the two and staggered breaks. Schools A and C were existing schools that have maintained their size into the new building, with school A the only school that does not have a sixth form provision (for 16-18 year olds).

Schools A, C and D, have all recorded GCSE results before and after the new school building, as they existed prior to the new building, enabling comparison to the BSF schools from the unified school database, shown in Figure 5.1. As school B was a new school when the building opened, the pupils started in year 7 and the school has been filling up year-on-year, with the first full year 11 expected in the academic year 2014-15, and hence the first full set of GCSE results. As such, it has not been possible to compare school B with the other three in terms of attainment. Noticeable from Figure 5.1 is that schools C and D have continually improved since the new building, whereas attainment at school A is starting to return to the level prior to the new school. However, all three schools are significantly above the mean found from the BSF schools.

# 6 Methodology – Interactive Space Analysis Tool

A key aspect of this body of research into the school built environment is exposing how the students perceive their environment. Through the use of questionnaires students are able to give feedback on the areas of the building that have been shown to be important in previous work, however it forces the students to think about aspects that may not be important to them and potentially overlooking the most important aspects to them. To produce balanced feedback, a new feedback tool has been created; the Interactive Space Analysis Tool (ISAT). The ISAT creates an immersive version of their building and allows the user to provide unguided comments on their environment, using the virtual building as a prompt. This use of the virtual building to capture the feedback enables the comments to identify visual aspects of their building that would are difficult to capture within questionnaires (such as layout or aesthetics). The ISAT also captures their movement through their building, enabling a detailed examination of not just how they feel towards their school, but how they interact with it.

This section describes the background to unguided occupant feedback, followed by the development of the ISAT, its usage within the four case study schools, and the method for analysing the resulting data.

## 6.1 Occupant Feedback

When capturing the views of the students regarding their school, the questionnaire is undoubtedly the one of most widely used methods. However, in compiling a questionnaire a number of assumptions are made about the student and their school, namely that their attitudes towards the building are broadly similar to those found by other questionnaires. This assumption equates to a selection of questions that capture the predominant issues identified in previous studies, but may miss key aspects of the building that are particular to an individual school. Techniques such as cognitive interviewing (Beatty & Willis, 2007; Willis, 2004) can improve the efficacy of any questionnaire, but will not improve the responses to context-specific issues. This has not stopped their popularity, with Peretti and Schiavon (2011) identifying 10 questionnaires for analysing the built environment, such as the BUS in the UK (Leaman & Bordass, 2001), and Berkeley's Centre for the Built Environment Indoor Environmental Questionnaire (IEQ) (Zagreus, Huizenga, Arens, & Lehrer, 2004). Their success largely relies on the ability of questionnaires to turn qualitative data into quantitative data for simpler analysis (Ben-Akiva & Lerman, 1985) and their high scalability.

The addition of open comment fields on a questionnaire can allow the respondent to comment on areas that were not included, or add qualifying thoughts, but the limited time and space afforded can reduce the comments to a side source of information. Moezzi and Goins (2011) successfully used Berkeley's Centre for the Built Environment (IEQ) (Zagreus et al. 2004) database as a basis for text mining free comments to determine key aspects in US office buildings. However the power for this type of study came from the sheer volume of responses; 192 buildings and 28,278 respondents.

The other widely used method for capturing the perceptions of the built environment is through interviews; whether simple one-on-one interviews or more elaborate interview techniques such as photo-surveys (Moore et al. 2008) or walkthrough interviews. Interview techniques have the significant benefit of generating rich data that is highly personalised to the situation, with respondents able to tell the research team what is most important to them. The trade-off in terms of research methodology is that interviews take considerably longer than a questionnaire, particularly in terms of analysis, likely reducing the size of the dataset. This reduced pool of responses can diminish the universality of any findings, and is often used to inform future questionnaires for wider, confirmatory analysis (Amaratunga, Baldry, Sarshar, & Newton, 2002).

The photo-survey method (Moore et al. 2008) engages the respondents with their environment by making them take pictures of the parts of their building/space that they feel are important (either positively or negatively). Adams et al. (2007) and Powell (2010) have both used this technique to explore cities, successfully gathering unguided feedback on their environments. The process for this work requires the distribution of disposable cameras, the development of the images, and, perhaps most importantly, an exit interview where each image is analysed with the respondent/photographer. Additionally, the use of cameras within a school can be difficult, even if they are handled by the students themselves, given the sensitivity of taking images of people under 16 years old. By bridging these issues with the photo-survey, the benefits of the open, unguided feedback can be used to explore the student perceptions further.

## 6.2 ISAT Requirements

Before development on the ISAT started, it was necessary to outline the principles of operation and the key outputs to ensure its usefulness as a research tool. As such, the following requirements were placed on the system:

- Analysis
    - Record background demographics of the user
    - Allow comments to be located to specific positions
    - Store images from the comment locations
    - Record movement through the building
- Interface
    - Be internet based
    - Simple/familiar interface
    - Accurately represent the building
    - Work on a number of devices
    - Load quickly
- Flexibility to analyse different spaces

With regards to outputs, a key aspect of all analyses is the ability to understand the demographics behind the data, requiring the ISAT to have a background questionnaire. This captures the same information as the student questionnaire in chapter 8.2; age, gender, and period of time in the building. The main data from the ISAT is in the form of free comments, with the students using the tool to immerse themselves in their building, prompting insight into their day relationship with the space. Using photo-surveys (Moore et al. 2008) as a start point, there are two parts that should be captured with each comment; the actual comment and an image of the area the comment is regarding. Additionally, to ensure the ISAT is representing a natural movement, the tool logs the spaces visited, which can then be compared to the space syntax measurements for verification.

To create a highly scalable platform, the ISAT is accessible over the internet. Other options for access include creating a desktop program or app for Windows or specific phone/tablet operating system. A desktop program would be specific to either the Microsoft's Windows operating system or Apple's OSX, automatically limiting the scalability or increasing the amount of work for development. Additionally, these programs will need to be installed on the computers prior to use, requiring administrator access, which may not be readily available within the schools. Similar issues exist when developing an app, with split markets (Android versus iOS) and administrator rights needed to install on phones. By developing a website, or web app, any device that is able to access a website can access the tool. This high availability is key to simplifying usage across a wide range of scenarios and in turn increasing the potential return rate. A key assumption of the ISAT was that the ease of data collection will result in a greater amount of data, overcoming any shortfalls in quality in comparison to interviews with sheer volume of responses.

By creating a simple, familiar interface, the learning curve for the tool can be minimised and the amount time potentially collecting relevant data can be maximised. For this reason, the ISAT is largely based on the successful Google Street View, although for simplicity it is limited to horizontal movement. The space itself needs to be the key element of the interface, providing the most immersive environment possible with the confines of an internet browser. As such the interface is dominated by the image of the space, with ancillary information pushed to the edges (see Figure 6.1 for a conceptual design of the ISAT). Interacting with the interface is through conventional techniques, predominantly using common mouse-based methods (for example clicking, scrolling, and dragging). As with the simple interface, this assists in shortening the period to be accustomed to the ISAT, increasing the response rates. Full instructions are provided upon logging into the tool, ensuring that everyone using the tool is aware of not only the intention of the ISAT, but also how to interact with it.

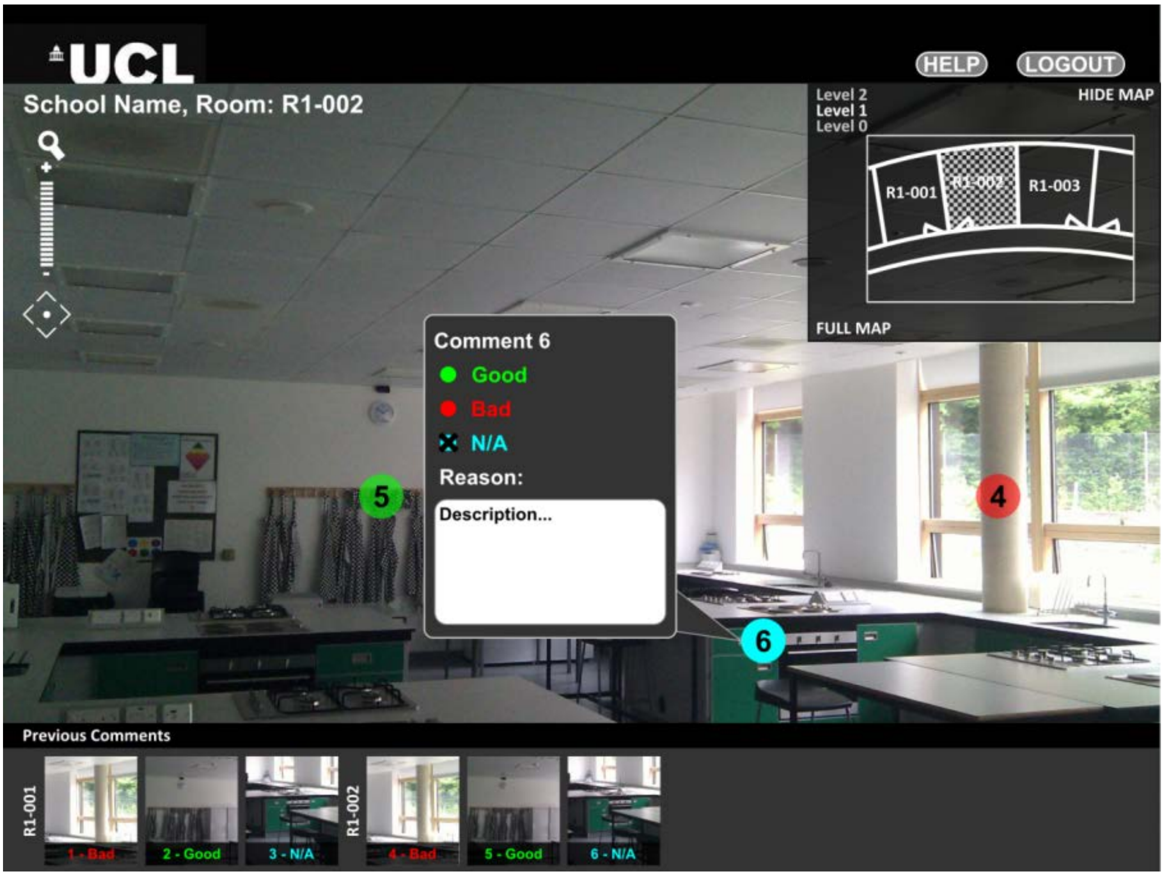



**Figure 6.1 – Initial design of the ISAT, with the space taking up most of the screen, the comment box 'hovering' close to the selected point, and previous comments by the user appearing at the bottom of the screen.**

Movement through the building is based on clicking a series of transparent links, representing doors or ends of corridors, but not distracting the user from the space. This creates a series of discrete spaces, each represented by a panoramic image as shown in Figure 6.2. The simplest method for creating these links is through experiencing the space through the tool and then assigning the most appropriate location. By carefully constructing the method of creating the building navigation within the same interface, it also greatly reduces the amount of development required as there will be no need for a separate building development system. This ability to alter the connections is locked behind a secure administration login to prevent modifications.

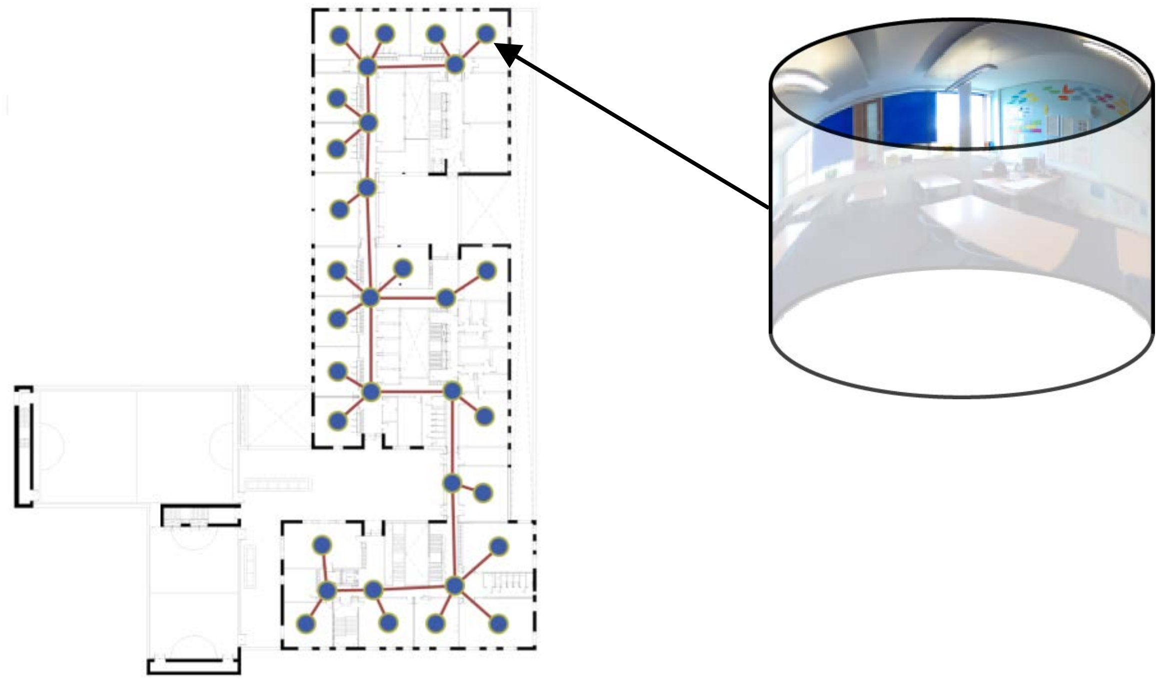


**Figure 6.2 – Each building will be represented by a series of discrete panoramic images that are linked together in the ISAT, mimicking the actual building.**

## 6.3 ISAT Development

The first decision when looking at developing a website or web app is where to host it, as this will reflect on the choices of database program and then the language in which the database is queried. The two most common combinations are PHP/MySQL (running on an Apache server), or ASP/SQL server (running on MS Windows server). The website was to be hosted on a MS Windows server and consequently the website was developed using the ASP/SQL server combination. As such, the ISAT was developed using ASP.net handling communication between the server and the web browser. All server-side code was written in C#, leveraging the .net framework. This was chosen over Visual Basic due to the increased flexibility and, as the code is more recently developed, the high level of continuing support.

The front end of the website is based on HTML, with CSS controlling the styling of the elements within. Enabling the ISAT to be more than a simple website clearly needs some interactive elements, far more than can be achieved with simple HTML and CSS (although limited interactive elements do exist, for example the dynamic pseudo-classes such as *:hover* in CSS (W3C, 2011)).

There are four predominant methods of producing an interactive website; Adobe Flash, Java Applet, JavaScript, and HTML5.

Adobe Flash has been widely used for interactive websites, is very flexible and ensures all the code behind the interactivity is hidden, with the Flash section of the webpage operating effectively as an embedded program within the webpage. However, Adobe Flash is not supported by a number of mobile browsers, with many websites moving away from it to ensure compatibility with the large market share now using mobiles and tablets (57% of people in Britain use their mobile handset to access the internet (Ofcom, n.d.)). This has substantial impact on the longevity of it as a basis for interaction in the internet. Java applets are very similar to Adobe Flash, with the website effectively hosting a program within the webpage. However, Java applets were the source of many virus scares, with malicious applets able to cause significant damage to the systems that access them. Accordingly, many browsers need explicit permission from the user to enable the applet to run. The ability to turn off applets permanently can be enacted by the IT administration, making running the ISAT potentially difficult on many managed systems. HTML5 (and CSS3) are designed to produce the same interactivity that was previously only possible in Adobe Flash and Java applets. HTML5 has had limited implementation in the main internet browsers (Internet Explorer, Safari, Chrome and Firefox), with none implementing the full HMTL5 standard as yet. While all browsers can be forced to understand the HTML5 standards, the additional layer of coding will introduce an unnecessary level of complexity.

Having explored the Adobe Flash, Java applets and HTML5 it was found that they are not suitable for development of the ISAT for the reasons described above. JavaScript provides a robust way of managing interactivity in a website, with good compatibility with all browsers (both desktop and mobile) and a strong developer network to assist with producing the code (there are over 747,531 discussions on stackoverflow[17], a widely used developers site). JavaScript is further assisted by the development of JQuery[18], a ‘wrapper’ that simplifies the common tasks used with in interactive web design. Using a combination of JavaScript and JQuery, the website has an interactive design that will be highly flexible.

17 As of 09/12/2014. Details can be seen here: http://stackoverflow.com/tags/javascript/info
18 JQuery can be found at www.jquery.com (last accessed on 09/12/2014)

## 6.4 ISAT Usage

Prior to the ISAT feedback sessions, each school was imaged using either a mobile phone running Photosynth[19] panoramic software (at schools A, B and D), or a specialist spherical imaging camera at school C (a Ricoh Theta[20]). This was undertaken during daylight hours close to the dates identified to ensure that the images provided an accurate reflection of the environment during the feedback sessions.

The best method for the ISAT feedback sessions, where the students would use the ISAT, was determined through discussions with the management at each school, identifying the ICT lessons as providing the necessary access to computers and the necessary numbers of students. Given the pressure to perform well in the GCSE exams, years 10 and 11 were deemed unable to dedicate time away from study by the schools, hence students from years 7, 8 and 9 undertook the feedback sessions. Three classes participated at each school, covering ages 11 to 14, with the students were given a maximum of 40 minutes to follow a typical day in the school using the ISAT. The tool was introduced by the researcher; describing the aim of the ISAT and how to interact with the tool. This was further reinforced by the initial login screens that state the purpose of the ISAT and gave clear instructions with illustrations on how to use the tool (shown in appendix H). During the feedback sessions, the researcher remained present to offer support on using the tool and to identify any software bugs that arose.

## 6.5 ISAT Comment Analysis

The ISAT is designed to generate unguided feedback, generating data that is highly personal to the experience of each student and each school. Due to this openness, the underlying structure to analyse the resultant data is effectively unknown, with the respondents creating their own structure. Defining a structure with the flexibility to encompass all aspects of the school climate is incredibly difficult, with Zullig et al. (2010) discussing the inability to define it within educational psychology over the 40-plus years prior to their attempt. Given this difficulty, an alternative method of generating an analytical framework for the data was proposed in the form of *grounded theory*.

19 See https://photosynth.net/ for further information (last accessed on 05/02/2015)
20 See https://theta360.com/ for further information (last accessed on 28/02/2015)

Grounded theory is ideally suited to exploratory data which has no defined theory as "*the conceptual framework is generated from the data*" (Stern, 1980, p. 21). By creating a framework for the collected data rather than force it into an existing one, the analysis is far more robust and relevant (Eisenhardt, 1989), ensuring all data is accurately represented, rather than 'forced' into an incorrect category. This has been used within the built environment before, with Sailer (2010) exploring the office environment through semi-structured interviews and applying grounded theory to generate underlying themes from these interviews. Applying the grounded theory principles and the open coding (Corbin & Strauss, 1990) method to the ISAT data creates four distinct steps:

1. Initial coding of each comment based on initial reaction
2. Recoding of the comments until no new codes emerge
3. Analysis of generated codes to create general *properties* that represent the codes
4. Generation of overall *dimensions* that group the properties into larger themes

Each comment can incorporate more than one property, and as such could refer to more than one dimension. Additionally, the sentiment of each property will be recorded, positive, negative or neutral, so that overall sentiments to each property and dimension can be analysed. For example, a comment could be *this room is hot and stuffy.* This comment could be coded as negative towards a temperature property, and negative towards an air quality property.

This will be enable comparison between the schools, identifying the performance of different strategies at each school. As the data itself will generate the properties, it can also be inferred that the properties identified are of key importance to them. Through examining the rate of occurrence across the four schools, patterns of student perception will be analysed, identifying the common elements as well the exceptional aspects of each school (whether negative or positive).

# 7 Results – Interactive Space Analysis Tool

The Interactive Space Analysis Tool (ISAT) was used at the four case study schools. To capture the unguided feedback of the students, focusing on their perception of the built environment. This section presents the results of the comment analysis within the ISAT, using grounded theory to categorise and group comments for easier analysis.

## 7.1 ISAT Overview

The ISAT was used at each school during the period of environmental monitoring, at the end of the heating season on the following dates:

- *School A*: 20th May 2014 and 21st May 2014
- *School B*: 11th April 2014
- *School C*: 29th April 2014
- *School D*: 15th May 2014 and 16th May 2014

Within each school, three ICT classes were used, with the number of respondents and total tags shown in Table 7.1. The comments received were split into relevant and irrelevant, with irrelevant comments ranging from those about the ISAT itself (discussed in section 11.7), about themselves, duplicates, blanks, and those that were unknown (such as seemingly random letters). These were removed from the analysis pool during the grounded theory process. Within each school, it can be seen that the percentage of relevant tags varies in each school (from 59.7% to 69.3%), with a mean relevance rate of 64.4%. Additionally, the number of relevant tags per user varies substantially (from 3.3 to 6.6 relevant tags per user), with a mean relevant tag rate of 5.1 tags per user. Schools B and C have the lowest relevance ratio, but have the lowest and highest total tag rate, 5.5 and 11.1 respectively, showing that the verbosity of the students is not necessarily an indicator of quality.

The ICT lessons used to undertake the ISAT were for years 7, 8 or 9, corresponding to an age range of 11 to 14 years old. Figure 7.1 shows the breakdown of users by school, with schools A, C and D all recording students as 15 or older. As this is beyond the age range of the classes, the users may be teachers, or simply students entering the wrong age (either deliberately or accidently). As such, these user ages cannot be used elsewhere in the analysis.

**Table 7.1 – Statistics on the number of ISAT tags received by school.**

| School | Users | Total tags | Total tags per user | Relevant tags | Relevant tags per user | Percent of relevant tags from each school | Percent of relevant tags from overall tags |
|---|---|---|---|---|---|---|---|
| School A | 48 | 410 | 8.5 | 284 | 5.9 | 21.8% | 69.3% |
| School B | 61 | 337 | 5.5 | 202 | 3.3 | 15.5% | 59.9% |
| School C | 71 | 790 | 11.1 | 472 | 6.6 | 36.3% | 59.7% |
| School D | 73 | 502 | 6.9 | 344 | 4.7 | 26.4% | 68.5% |
| *Total* | *253* | *2039* | - | *1302* | - | - | - |
| **Mean Average** | **63.25** | **510** | **8.0** | **326** | **5.1** | - | **64.4%** |
| Range | 25 | 453 | 5.6 | 270 | 3.3 | 20.7% | 9.5% |

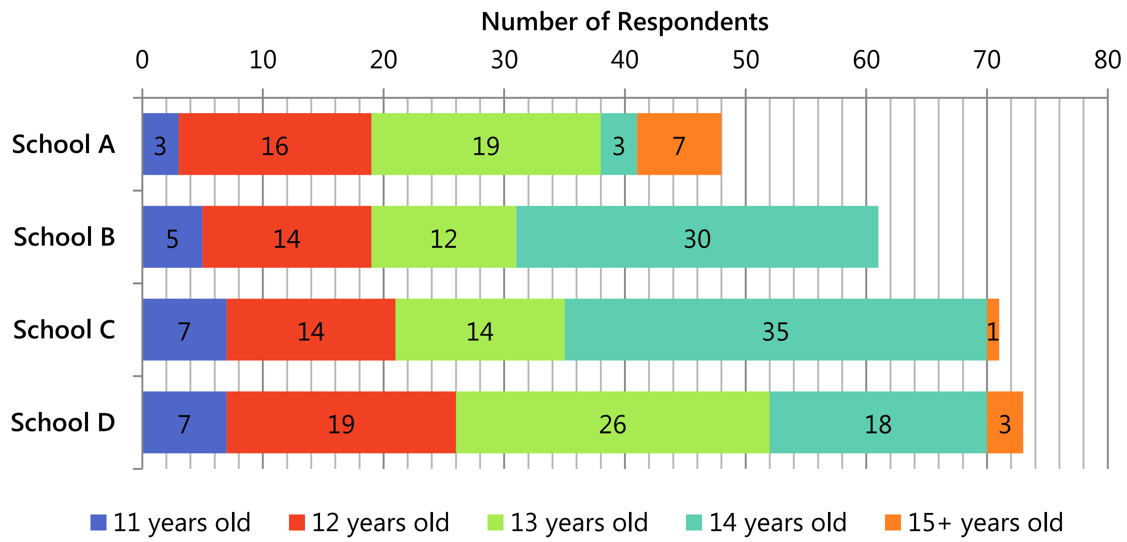



**Figure 7.1 – Graph showing the ages of ISAT users at each school. Note that the maximum age of respondents in the class was 14, so all responses for 15+ years old cannot be relied upon.**

Each school suggested the ICT lessons used based on availability, which does not necessarily represent random sampling. This is clear from the gender breakdown at each school (see Figure 7.2), with more male users recorded than the percentage recorded by the DfE (figures from (DfE, n.d.-a) and shown in Table 5.1).

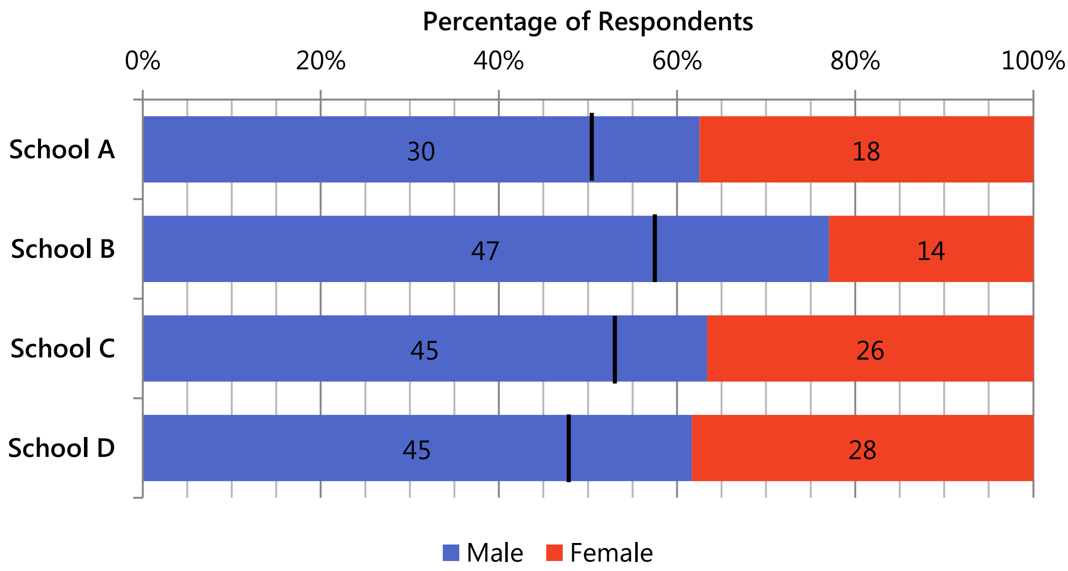



**Figure 7.2 – Breakdown of gender of ISAT user by school, with black line indicating reported split in gender of each school.**

## 7.2 Grounded Theory Analysis of ISAT Tags

The comments of each school were collated together using MS Excel 2010, as a direct export of the SQL database underpinning the ISAT. Using the Grounded Theory methodology, the comments were then read through and a column added for each new code. This was repeated until there were no new codes generated and existing codes were not applied to the tags. The first outcome of this exercise was to remove all the irrelevant tags, as noted above in section 10.1, leaving behind only those that provide tangible information about the school. As this is the first time the ISAT has been analysed, there was no presumption of an underlying structure to the comments, instead an emergent structure was developed that encapsulated all of the comments, generating four main dimensions (plus a dimension about the ISAT itself) as shown in Figure 7.3. The four dimensions of interest were as follows:

1. *Building Management* – covering facilities management, furniture, fittings and equipment (FF&E) and ICT
2. *Environmental Performance* – the internal environment of the school
3. *School Design* – the physical building design
4. *School Management* – closely related to the school climate

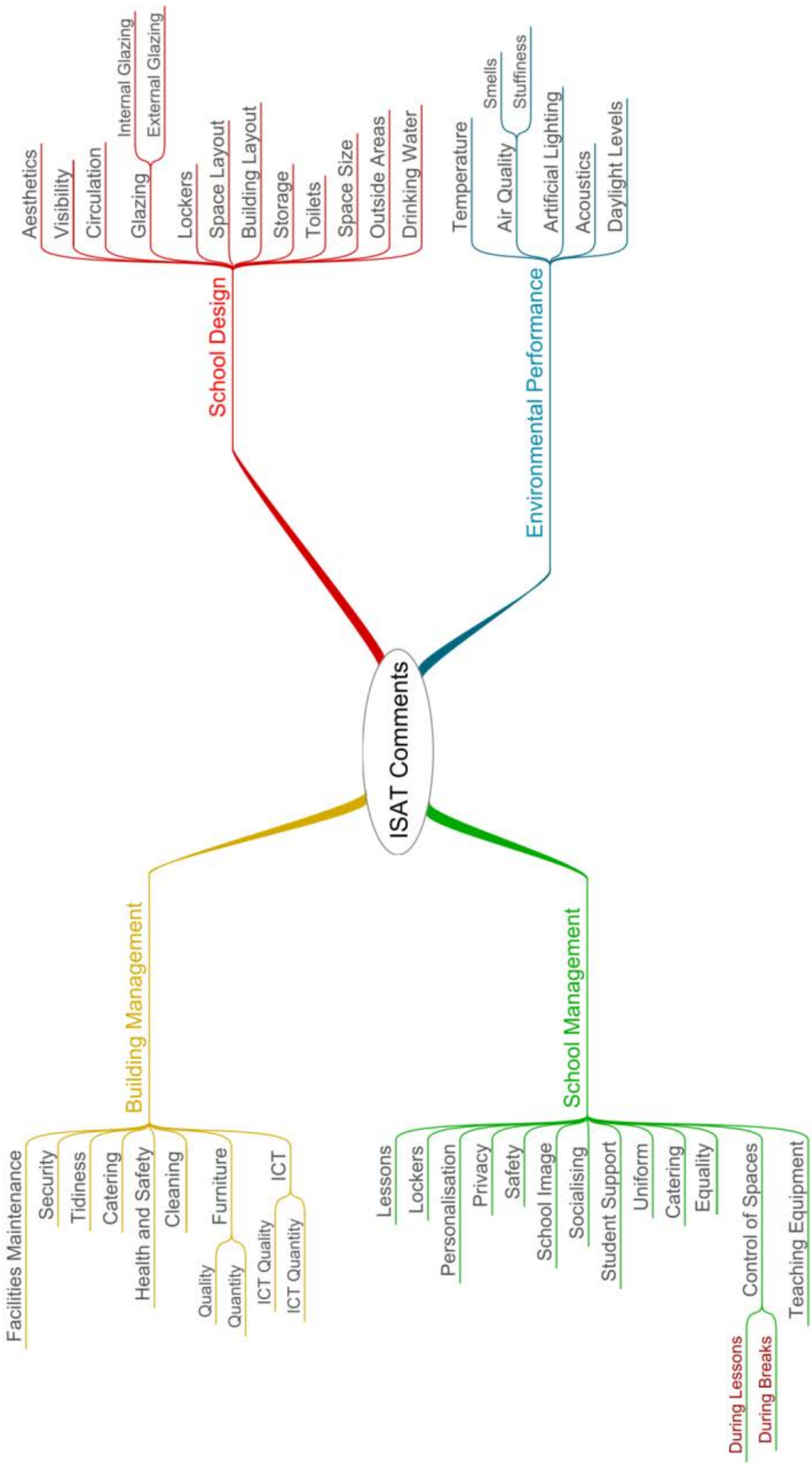



**Figure 7.3 – Map of the codes generated through the analysis of the ISAT results, with the five main dimensions and the dimensions that comprise them (note that irrelevant comment codes have been omitted)**

Each of these dimensions has a varying number of properties, coded as either positive or negative within the worksheet. Additionally, glazing, air quality, furniture, ICT, and control of spaces have sub-properties, with the additional nesting making it easier to spot the underlying pattern.

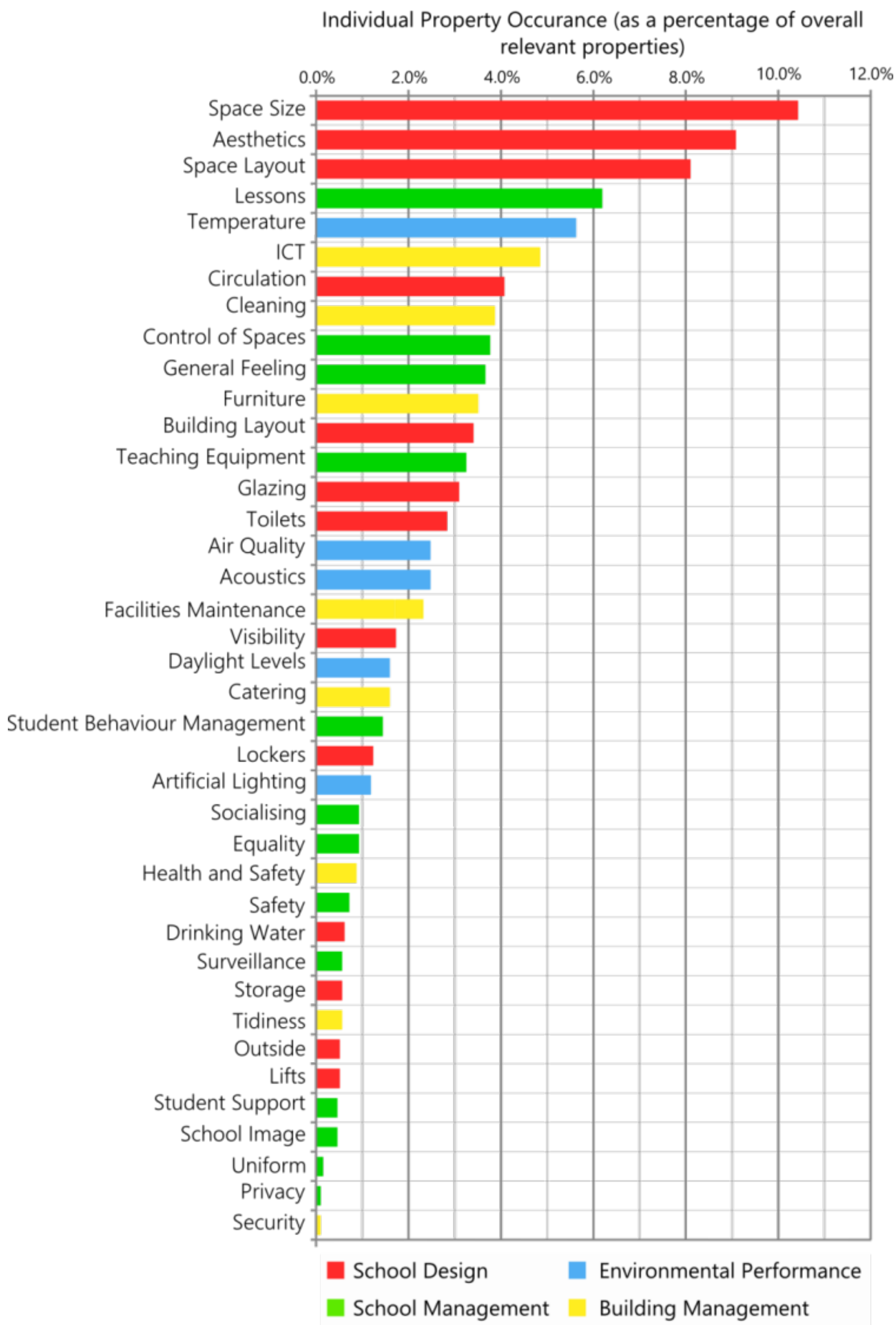



**Figure 7.4 – Graph showing the relative property occurrence within the relevant tags recorded using the ISAT, colour-coded according to the four main dimensions**

As all comments recorded by the ISAT are unguided, the magnitude of comments for a specific property can be treated as its relative importance. By comparing the magnitude of comments a scale of properties can be developed showing the key aspects of the school across all four schools (shown in Figure 7.4). As a comment can relate to a number of properties, this magnitude is calculated as a percentage of overall property occurrences.

Examining Figure 7.4 shows that the top three occurring properties relate to the building design dimension; space size (10.2%), aesthetics (9.1%), and space layout (8.1%), with lessons and temperature the next most common properties (6.2% and 5.9% respectively). Overall, the dominance of the school design dimension is clear, with twice as many occurrences as school management, the next most regularly occurring dimension (see Figure 7.5). Both school design and school management have a similar number of properties (13 within each), whereas building management has 9 properties and environmental performance has only five properties. The number of properties highlights the importance of the dimension, but despite school management and school design having the same number, school design clearly attracted more responses. The high occurrence of the school design dimensions shows the influence of the visual environment within the ISAT, with the images of the space the only prompt the students received. As such, it is expected that the visual aspects of the school have a high occurrence, but relatively high occurrences of the other dimensions that are not tangible within the ISAT demonstrates the students' engagement, as well as their importance to the students.

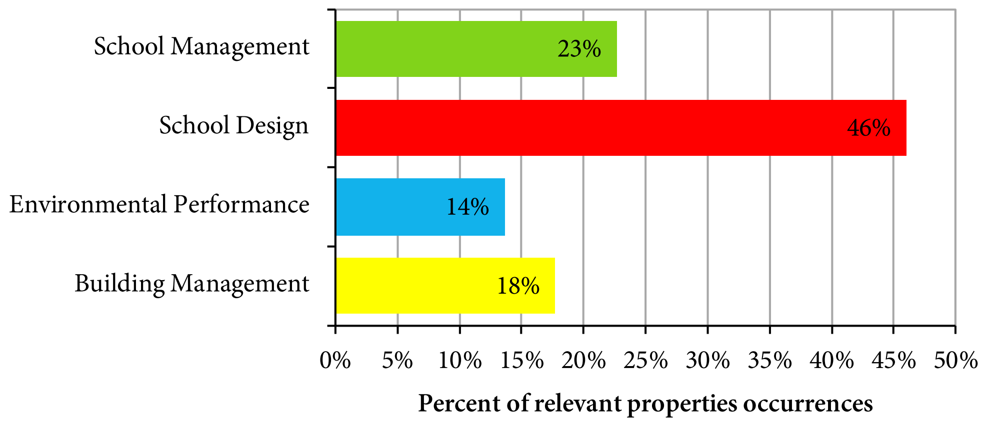



**Figure 7.5 – Graph showing the percentage of relevant properties recorded for each dimension**

Although the ISAT instructions ask for an equal number of positive and negative comments, there is a significant bias towards negative ($N(positive) = 704$, $N(total) = 1934$, $p < 0.0001$). For the purposes of assigning importance within comments the polarity has not been important, with the quantity of comments enough, however to understand the actual opinions of the students the polarity of the comments has to be reintroduced. Figure 7.6, Figure 7.7, Figure 7.8, and Figure 7.9 show the breakdowns of each dimension, with the values shown as a percentage of the overall dimension occurrences within the tags (i.e.: the total negative and positive result for each school will sum to 100%).

## 7.3 Exploration of ISAT Comments

The properties for the *school design* dimension represent nearly half of the overall comments about the school. As noted earlier, the school design has the three top occurring properties, space size, aesthetics and space layout, and they dominate Figure 7.6. School A has significantly more comments than the other three schools for both space size and space layout due to the number of negative comments received, with these properties highly correlated (28 tags occur in both properties). Comments such as "*Art room is to small you cannot even walk around in it when there is a huge class full of students*" (Student at School A), and "*It's too crowded, to hot, and really hard to get around*" (Student at School A). Conversely, at School B, the comments are more favourable: "*Great place for lockers as it's not as crowded as other places*" (Student at School B).

From the quotes at school A, it is clear to see the overlap between layout and space, however the property space layout has other implications at School A, with the open plan classrooms dominating the comments: "*It's too small and its distracting looking at others outside*" (Student at School A), "*Gets too noisy during my English lesson because it is a wide open space so I can hear all of the other classes screaming*" (Student at School A). This visibility between spaces was favourable at School B: "*I like how you can look in the window to see if you teacher or friends are in the class*" (Student at School B). With as many positive as negative points, the students at School D found the spaces tidier, and better laid-out: "*This room is very well spaced and well organised.*" (Student at School D).

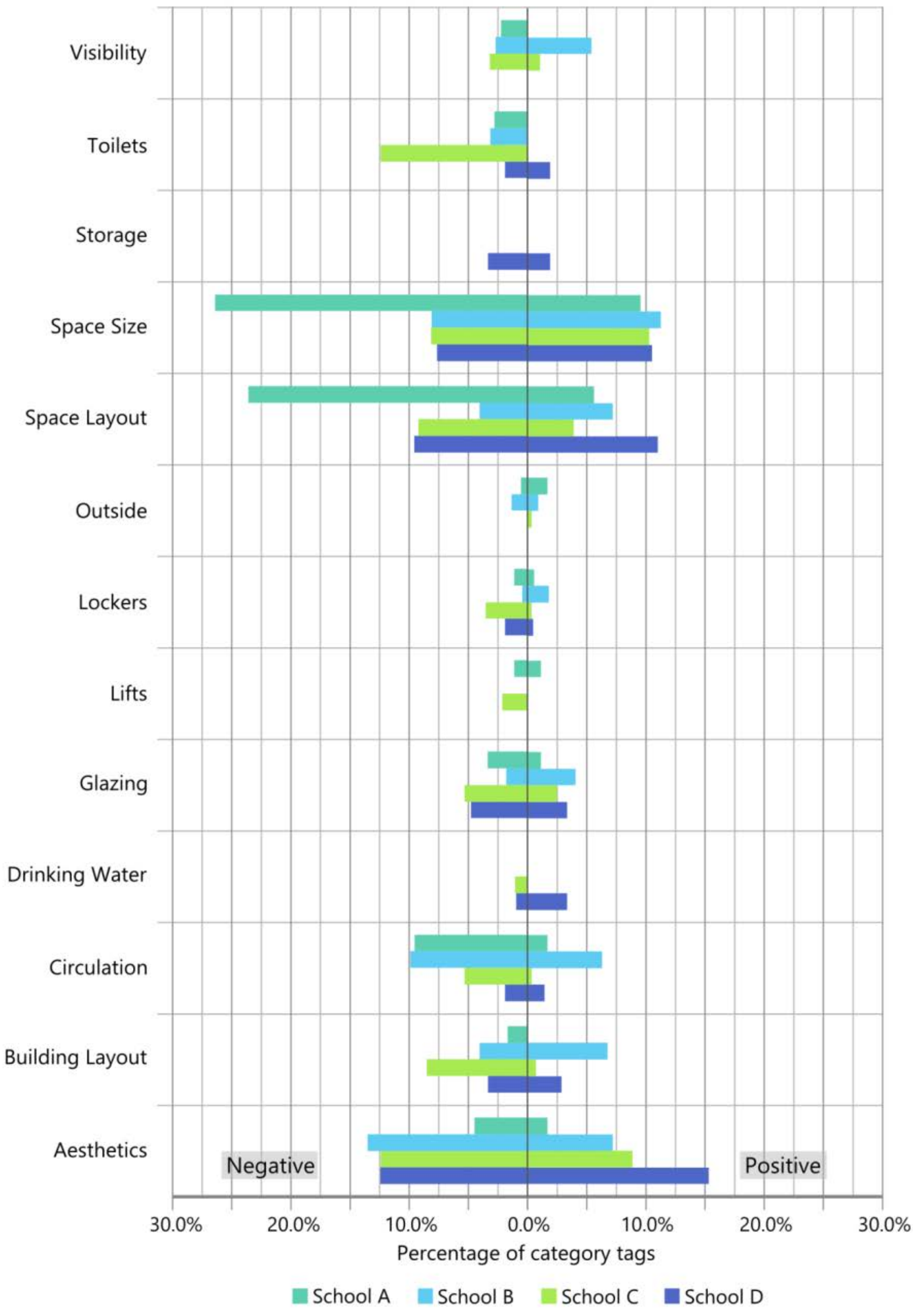



**Figure 7.6 – Polarity and percentage of properties recorded in tags from ISAT, for *School Design* dimension, shown as a percentage of total dimension occurrences in each school**

Continuing with the highest rated properties, aesthetics was very mixed at all four schools, although overall negative. At all schools there was a dislike of the lack of colour within the spaces: "S*ame colour in every room*" (Student at School B), "*Really plain columns.*" (Student at School C"), "P*ut more colour in the room*" (Student at School D). However, at School D, the students liked the display boards and personalisation, which may point towards a solution for the perceived lack of colour: "*Really nice art room, students' art all over the walls and outside*" (Student at School D), "*I like the posters*" (Student at School D).

Circulation was found to be a key property of the School Design dimension, with School A and School B both rating it negatively. At School A, this is linked to the overcrowding between lessons "*Gets hard to move around along these pathways since students going to their lessons*" (Student at School A). Although at School B the comments linked to the movement between lessons as well, they are more specifically about the one-way system the school has put in place: "*One way system causes: packed doorways, accidental putting off of the alarm, possible health and safety violation, unnecessary corridor cards/lateness*" (Student at School B).

At School C there was a clear issue about the Building Layout, with a number of students noting the unusually placed columns: *"I walked into this pillar once because it's in a random place*" (Student at School C), and "*Seriously what's up with all these random pillars*" (Student at School C). School C also had a number of negative comments about the toilets, something that the other schools did not receive. From the comments it is clear to see that there is one set of toilets at the school that is dominating the feedback (see the brightest red space to see the space adjacent to these toilets in Appendix F). These toilets were found to be unclean and closely related to disruptive behaviour, notably smoking: "*Toilets are always stinky and never get cleaned and always stinks of cigarettes*" Student at School C), "*The toilets are always used for smoking*" (Student at School C). Of all the four schools, only School C has traditional, closed style toilets, as opposed to the other three which have individual, closed cubicles onto an open space. The lack of comments at the other three schools confirms the success of these layouts relative to the traditional closed toilets.

Within the Building Management dimension (shown in Figure 7.7), one of the most popular properties was regarding ICT, particularly at School D. Much of the negative comments about the ICT surrounds the quality of the ICT provided: "*Need better laptops. Faster, problemless ones*"

(Student at School B), "*Printers break all the time!*" (Student at School D). There was also a notable number of comments regarding Apple computers, particularly where they have been provided for other departments such as music: "*More Apple PCs*" (Student at School B), "*Need new and better computers such as iMacs*" (Student at School C), and "*Why should music have the better computers but the ICT students have the bad ones. With missing keyboards, mice, letters on the keyboards.*" (Student at School C).

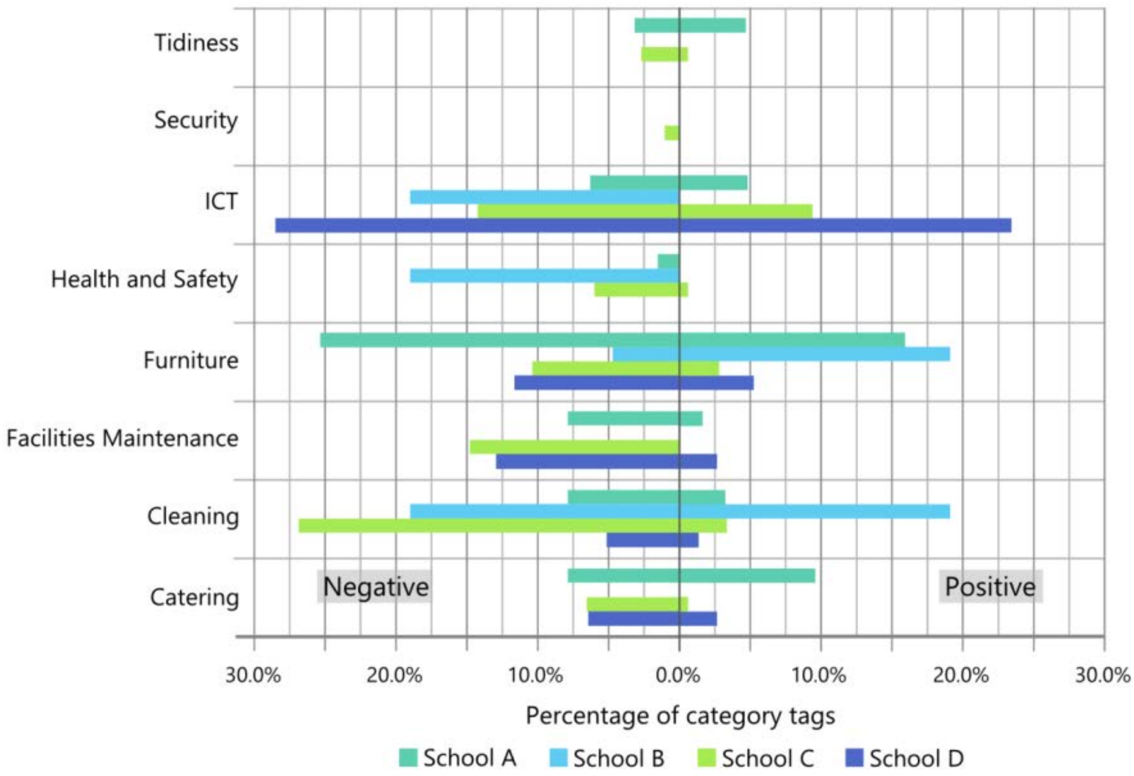



**Figure 7.7 – Polarity and percentage of properties recorded in tags from ISAT, for *Building Management* dimension, shown as a percentage of total dimension occurrences in each school.**

Cleaning of the schools was another popular property (although very negatively), with the two main spaces identified as areas for concern: toilets and the dining areas. At School C, the negative comments were closely linked with anti-social behaviour occurring in the toilets (see above), but there were many comments about the canteen area: "*Tables are always messy when we go for lunch*" (Student at School C). Due to the number of pupils and the size of the dining space, there is more than one sitting for lunch, with staggered lunch breaks to prevent overcrowding. This is likely the source of the mess as the students arrive. The cleaning of the toilets was also a key topic for the other schools, but with fewer comments that at School C.

The quality of the chairs contributed to the number of comments regarding furniture, which is to be expected given the amount of time the students will spend interacting with them. The chairs at School A were particularly divisive with some students rating the chairs as comfortable and others clearly unhappy with the furniture: "*These chairs are horrible they hurt your back*" (Student at School A), whereas the chairs at School B were found to be very comfortable. At School C, there were a number of complaints about the quality of the stools, with many comments noting that the stools were in need of repair: "N*ew stool needed because most of them are broke*" (Student at School C).

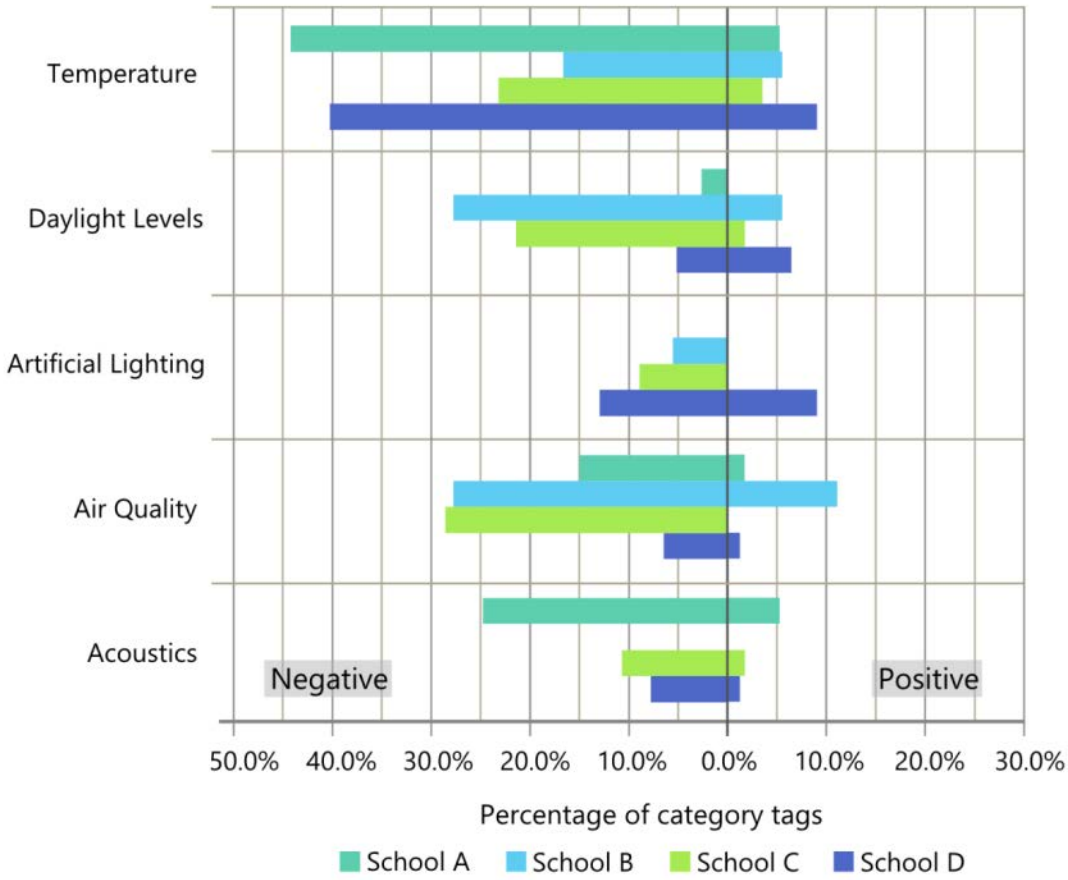



**Figure 7.8 – Polarity and percentage of properties recorded in tags from ISAT, for *Environment* dimension, shown as a percentage of total dimension occurrences in each school.**

Comments regarding the catering nearly all relate to the quality of the food served, with School C receiving more positive comments than negative, although room for improvements were identified: "*…if this school had KFC it would be the best school ever*" (Student at School A). Additional aspects with regards to catering focused on the paying and queuing for food, with more credit machines required and long queues experienced. Within the facilities management property, a variety of issues were exposed; the white walls highlighting dirt at School D, broken blinds at School C, and maintenance of the grounds at schools A and C. Comments such as "I *love being outside in the summer, the grass is cut good and you can chill out with your friends on the hill*" (Student at School A), highlight the importance of the outside spaces to the students, particularly for socialising.

From Figure 7.5 the temperature property can be seen as an important factor not just within the environmental dimension, but also the building as a whole. As can be seen from Figure 7.8, the comments about temperature are overwhelmingly negative, particularly at Schools A and D. The students at School D felt the classrooms were too hot: "*When we do reading I prefer doing it in* [the library] *rather than the classroom because it doesn't get hot*" (Student at School D). At School A, the classrooms were also found to be too hot, but conversely the communal areas, notably the central atrium, were found to be too cold: "*The heart space is really cold and sometimes I think that the school doesn't have heaters*" (Student at School A). Another key area with apparent temperature issues is the drama studio, which got mixed comments of being both too hot and too cold from the students, but with some of the students linking the overheating to when it is being used as for dance: "*The dance studio is really good, but it can use some air fans because sometimes when you are dancing as it can get really hot in there*" (Student at School A).

Linked to the temperature, a number of comments were made about the air quality, usually through feelings of stuffiness or smells. Not surprisingly, the toilets at School C featured, with the smell of smoke mentioned repeatedly. At School B, the classrooms were felt to be stuffy, with more openable windows identified as a solution, which is echoed by the comments of another student at School D: "*I sit here because I have enough daylight that makes me see my work and when the window opens I get enough fresh air*" (Student at School D).

Daylighting of the spaces was widely negatively mentioned at School B and C, focusing on the blinds and the ability to block the daylight: "*The blinds let in so much light*" (Student at School B) and "*Useless blinds, can't watch video unless there is a solar eclipse*" (Student at School C). The quote from School C points to the need to watch videos during a typical lesson, using interactive white boards that can be washed out by strong daylight. Good blinds are therefore particularly important, with daylight noted to be beneficial by the students where videos are less used, notably art and PE: "*Favourite room because it's a good place for art. There is sunlight and it is perfect*"

(Student at School B), "*Massive – great for PE lessons. The light from the sun roofs is great.*" (Student at School D).

As can be seen from Figure 7.8, while three school noted the acoustics of the building, School A had considerably more than the others. This centres on the noise within the open plan spaces "*It has 3 open class rooms which is bad because it gets too loud for lessons and is hard to learn.*" (Student at School A). Within School C another acoustic issue is notable, with the acoustic separation between rooms allowing sound to link between spaces "S*mall classrooms, thin walls you can hear everything through them*" (Student at School C). This is likely caused by the flexible design of the building, with all internal walls non-load bearing, allowing the layout to be reconfigured at a future date.

Figure 7.9 covers the school management, including aspects of the schools that are not directly related to the building, but were deemed important enough to make largely positive comments about. However, some of the properties are closely related to the building, notably, socialising, control of spaces, and teaching equipment. Within the teaching equipment property, many of the negative comments were regarding the under-provision of clocks, but at School C there were comments about the quality of the science equipment.

The properties of socialising and control of spaces are connected, the latter relating to how the school manages the students within the building. Within School A, the students enjoyed the sense of identity they got from the individual school wings, but also appreciated the central atrium space as somewhere to socialise: "*the layout of the school is perfect but* [their school] *is amazing the building brings us all in to one humongous family all to one and it's the perfect place to learn and achieve high in life* ☺" (Student at School A). Where movement is controlled at breaks, such as schools C and D, the students are less enthusiastic: "*At break have to be in library or canteen, and older students have nowhere to go*" (Student at School D), "*The year 8s are always coming in at the same time as year 9s are going out*" (Student at School C).

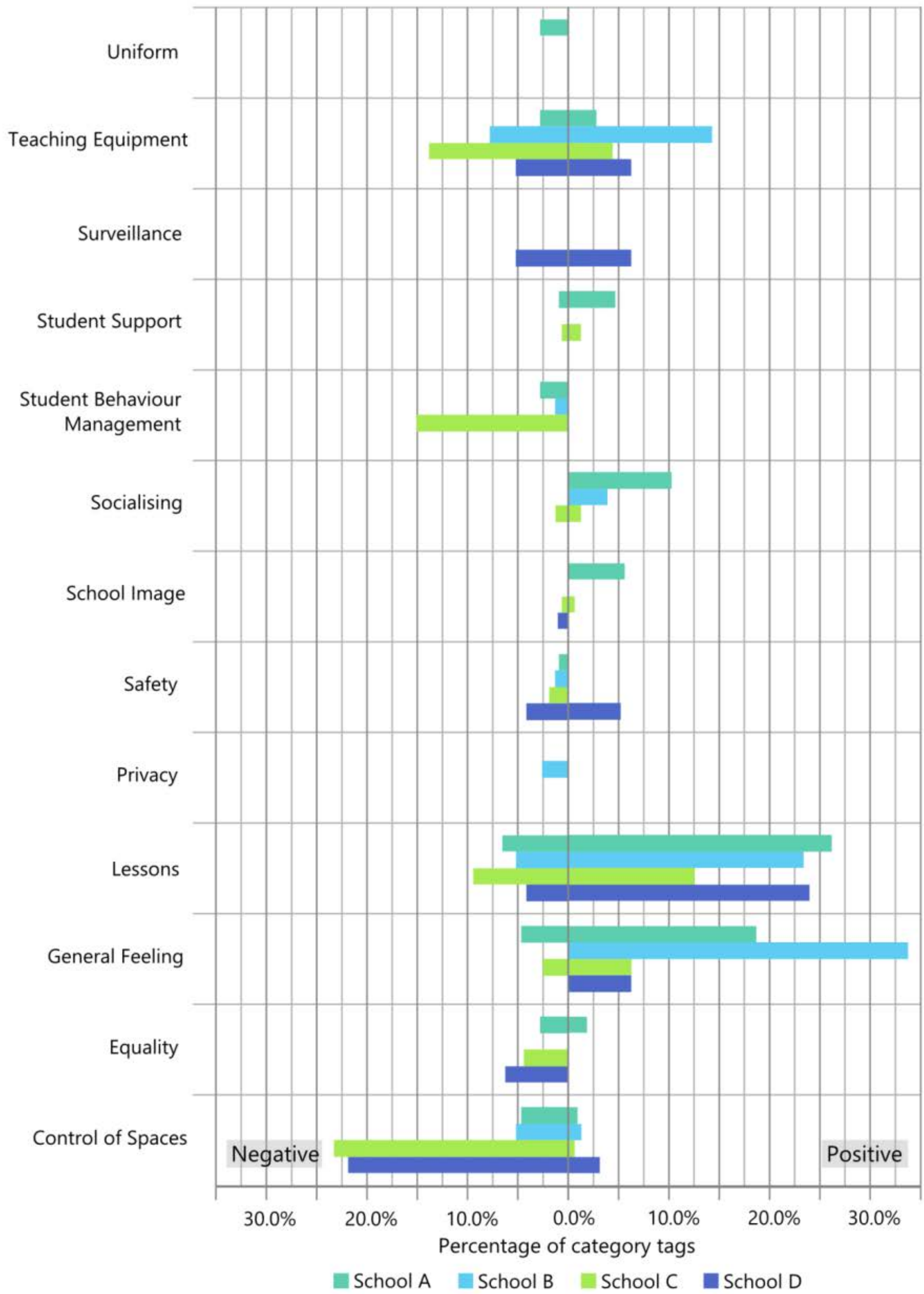



**Figure 7.9 – Polarity and percentage of properties recorded in tags from ISAT, for *School Management* dimension, shown as a percentage of total dimension occurrences in each school.**

## 7.4 Feedback on ISAT

Immediately after the students finished using the ISAT, they completed the feedback questionnaire, rating their experience of using the tool (questionnaire in Appendix L). Respondents rated the ISAT well (see Figure 7.10), particularly the ease of making a comment and the clarity of the instruction. The students also reported that the tool helped them think about their building and that they enjoyed using the tool.

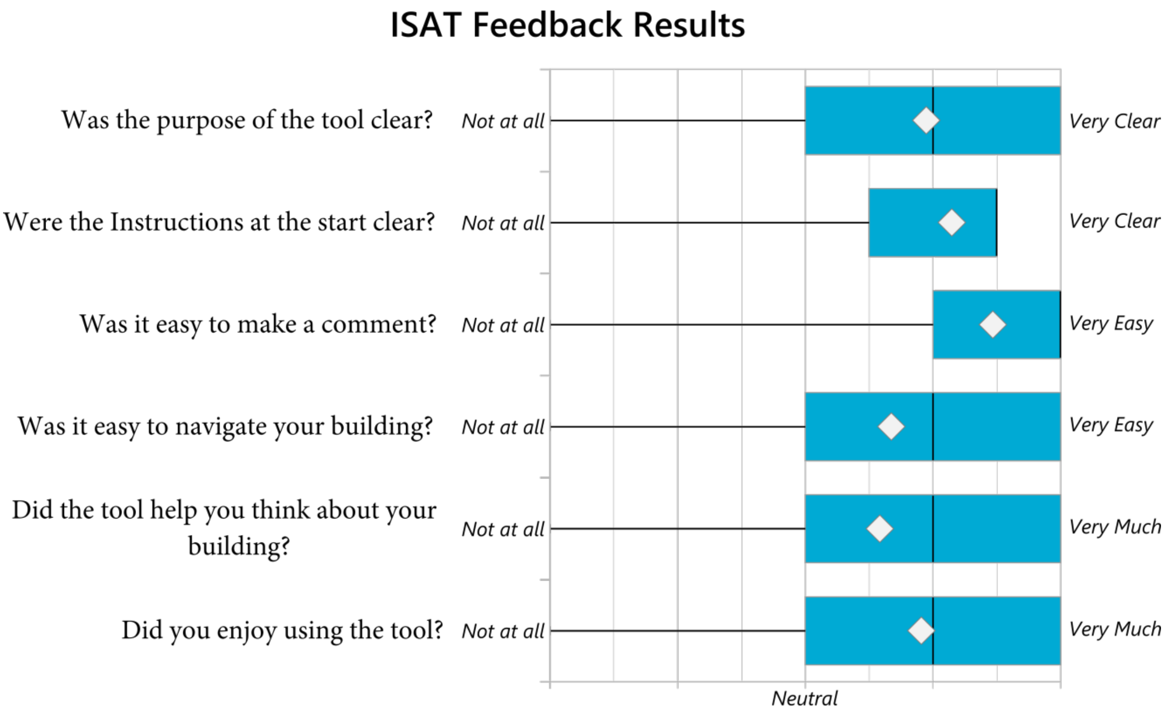



**Figure 7.10 – Summary box plot showing results of feedback questionnaire from all four schools following use of ISAT (N = 235)**

When asked whether they felt they had enough time (40 minutes), 58% said they felt they had enough time, indicating that for a large building such as these schools, to receive complete responses from all the students, more time may be necessary. In addition, 63% indicated that they would like more spaces included in the ISAT version of the school, with a majority requesting the outside spaces that were not included in the study, as well as singling out certain rooms that they felt were important (notably the dance studio at School B). When asked whether they encountered any problems during use, only 22% said they had any issues, with many focusing on issues of poorly 'stitched' images from the use of the application on the mobile phone. In School C, which used the spherical camera, only one problem was encountered with the images (too much exposure), however the ISAT was perceived as slow within School C, taking away from the users' experience. This was caused by poor ICT hardware as the machines were over 5 years old, and running an early version of Internet Explorer 8.

## 7.5 Summary

The ISAT was used at all four case study schools, enabling the large scale collection of unguided feedback from students as well as navigation data. The navigation data was compared to the VGA results from section 7, enabling an understanding of the motivation behind the movement. Feedback from the students was analysed using grounded theory to draw out the underlying themes within the data, enabling the use of statistically robust multi-level modelling to find significant links between ISAT comments and the measured environment (both environmental measurements and occupant feedback).

*The ISAT enables large scale open-ended feedback*

The ISAT collected a total of 2,309 tags, with 1,302 rated as relevant from 253 students, corresponding to an average 5.1 tags per student. To collect this many responses took 12 hours (3 hours at each school) which is the equivalent of spending less than 3 minutes with each student. This short period of time for each student would make a successful open ended interview very difficult, showing that the ISAT enables a larger scale of data collection than would otherwise be possible. This scale is at the expense of no ability to ask follow up questions for each student.

*Visual aspects were the most important aspects of the building to the students*

The ISAT is a visual tool and as such it allows feedback on the building in a way that would be difficult to capture in a conventional questionnaire (as used in chapter 9). This led to the space size, aesthetics, and space layout being rated as the most important aspects of the building across all four schools from the perspective of the students. There is clearly a bias arising from the nature of the ISAT, but it does provide a method for exploring occupant feedback on specific building form issues.

*Students struggle to isolate the building from the school*

The instructions for the ISAT, both verbal and as part of the introduction, ask for perceptions of their building only, however significant numbers of responses were regarding the lessons themselves (the fourth most regularly occurring property) or the activities they undertake in the building (where they socialise for example). This difficulty in separating the building from the activities inside it shows that they are not strictly two entities in the minds of the students, but a singular school, where the school climate influences the opinions of the building. Without the open-ended format of the ISAT, it would have difficult to ascertain the influence the school has over the opinions of the building, but the quantity of responses regarding the school management shows that it is difficult to explore the building in isolation.

*Students are able comment on building aspects that are not experienceable in the ISAT*

The importance of the temperature despite the inability to physically experience the temperature through the ISAT shows how important it was considered by the students, although the maximum temperatures measured at each school did not exceed 27 °C. Other key environmental aspects, notably air quality and acoustics, were also were also noted by the students. As these are not directly experienced through using the ISAT, it highlights how important these aspects are to the students, potentially more so than the visual aspects.

# 8 Methodology: Social Aspects of Space – Space Syntax Analysis

Understanding how the school building influences the occupants needs to include a method of quantifying the built form, whether this is a simple judgement as in the work of Barrett et al (2013), or a more rigorous system such as the tools of space syntax. Without capturing the detail of the built form, the interaction of the students and their building becomes difficult, if not impossible, to analyse. Within this case study, the principles of space syntax will be applied to each school building using Visual Graph Analysis (VGA) as set out by Turner and Penn (Turner and Penn 1999), with the visual nature making comparisons less abstract than other space syntax methods. This section and the following results chapter will focus purely on the space syntax analysis of the space and the comparisons between the schools. This space syntax data will be used in later chapters with the additional analysis data to further understand the influence of the building.

## 8.1 Building Modelling

The VGA analysis was undertaken using specialist software DepthMapX (Varoudis, 2012), which has been widely used within the space syntax community and provides accessible tools to generate many of the common space syntax measures. Modelling of the schools within this work follows the instructions given within Turner's instructions for DepthMap (Turner 2004). The VGA was undertaken using .dxf drawings that were validated with the buildings, ensuring any changes to the building since the final drawings were captured in the space syntax model. The drawings were stripped back to lines representing the outlines of walls, with each room drawn with a closed door. All features that are not visible at 1.5 metres above floor height were removed, representing the height of the camera in the interactive space analysis tool (see Chapter 10), most notably this included all desks and chairs. Each closed room was treated as a separate convex graph, with a link created that represents the continuation of vision (see Figure 8.1) as used in the work by Sailer (2010). While the rooms could be modelled with the doors open, this is not a true representation of the visual environment as most doors are shut during lessons. Using the links allows the visual continuity, but without breaking the realism of the VGA.

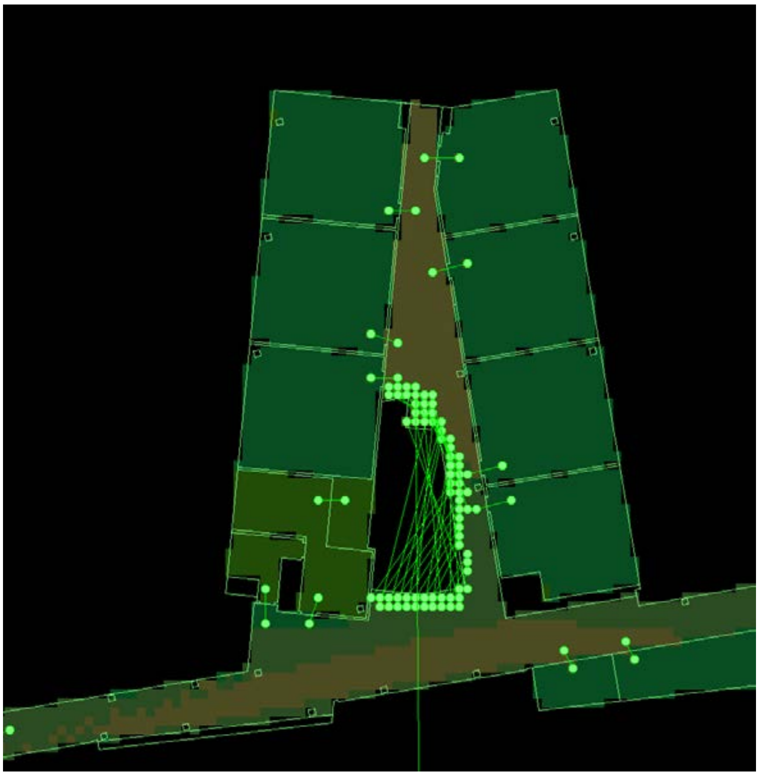


**Figure 8.1 – Screenshot of DepthMapX (Varoudis, 2012) showing the links (in green) that represent continuations of visibility, with doors and an atrium shown in this image**

Each school has at least one atrium of some form, which is somewhat problematic to model within DepthMapX as walls are treated as barriers to vision and including the atrium void as a space that could be occupied would lead to misleading calculations. As with the doors, the linking tool was used to create visual links between each side of the atrium with the other sides, as shown in Figure 8.1, allowing visual continuity without invalidating the calculations.

While vision between floors is possible, this has not been modelled in this VGA. As the link tool creates a two-way link between spaces that represent each linked space as mutually visible, it implies that the space visible from the higher floor is just as visible as those from the lower floors. This logic is flawed, with an isovist in 3-dimensions representing a cone of vision that will not propagate horizontally in the same manner as a simple 2-dimensional isovist between floors (Varoudis and Psarra 2014). I.e. when looking up at a higher floor, the area visible on the upper floor will be much less than a person stood at the edge of the upper floor. Initial testing showed that these links between floors had no noticeable influence over the results of the VGA, so have been omitted due to the questionable validity of its inclusion. This 2-dimensionality also creates difficulty when attempting to represent the movement between floors. Using the same linking tool as used for the doors and the views across atria allows continuity between spaces, with a link provided between the top and bottom of flights of stairs.

While the whole of each school could be modelled, it is important that the VGA map represents the spaces accessible to the students as this is from their viewpoint. As such, all spaces that are not immediately accessible by the students have been omitted (plant rooms for example), however, staff areas that have occasional visitation by the students have been included. In addition, the 2$^{nd}$ floor of School A has been omitted as an outlier as it contains only one space, the art room, which has a large effect on the visual connection through the school and skews the results.

## 8.2 Space Syntax Analysis

Once the buildings have been modelled in the DepthMapX software (Varoudis 2012) to create an approximation of the built forms, the schools were ready to be analysed using the space syntax tools. There are currently few studies of schools using space syntax with which to compare the case study schools, and those previous studies have focused on the integration measure of the space. As such, this work used the integration measure to enable comparisons with previous work, but also will focus on the mean depth which provides a more comprehensible measure. In addition to the mean depth and integration, this study will also evaluate the intelligibility of the spaces, creating a measure of the complexity of the built form.

### 8.2.1 Integration of spaces

The first analysis step was creating a graph of the Hillier-Hanson (HH) integration using the in-built functions of DepthMapX. The integration of a space represents its centrality, with lower values indicating the space is more isolated from the rest of the building. To understand each school, the integration has been analysed using a radius of ‘n’, creating a *global* integration value that represents the whole building rather than focusing on any local effects. To compare each school, the distribution of integration at each point within each building has been compared using box plots, with graphical layouts used to highlight areas of low or high integration. Within this study, the integration values are used to compare the building to previous research, with much of the previous work focusing on integration rather than other measures (notably Pasalar (2004)).

### 8.2.2 Intelligibility

Using the global integration values of each point within each school, the intelligibility was found by regression analysis using the connectivity values for those points found from the DepthMapX software. The intelligibility quantifies the wayfinding and orientation of the building that is inherent to the building layout, with lower values suggesting that local visibility does not follow the same logic as the rest of the building. The $R^2$ result of the regression at each school represents the overall intelligibility of the building form, with higher values representing a higher level of intelligibility.

### 8.2.3 Mean depth

Although much of the existing research into schools using space syntax tools has focused on integration and intelligibility, the more recent work of Sailer (2010) has shown that mean depth can also be a useful metric. The mean depth quantifies the mean number of visual turns from a point to each other point within the building, representing the visual separation from the rest of the building. The process of generating integration and mean depth is essentially the same, with the integration normalised to show centrality. However, due to the relative ease of analysis of mean depth it has been used in tandem with the integration to enable a greater dialogue of the building layout.

As with the integration, the mean depth was analysed using a *global* radius, capturing the whole influence of the building rather than local features. At each point in the building layouts, the mean visual step depth to the rest of the building has been calculated by DepthMapX. Each school will be compared using box-plots and graphical layouts to highlight the distribution of the mean depth for each point.

# 9 Results: Social Aspects of Space – Space Syntax Integration

Within this chapter, the four case study schools are explored, using the VGA methods from spaces syntax to compare the different built forms, starting with the integration, followed by the intelligibility and then the mean depth. Both the integration and the mean depth capture the same aspect of the layout, with the integration used to compare the buildings to previous studies, and mean depth used to analyse the built form.

## 9.1 Integration of spaces

Using DepthMapX (Varoudis, 2012), the integration (HH) for each school was calculated, enabling comparisons between the buildings. The integration quantifies how central a point is within the building, with low figures indicating that a space is more remote. As can be seen from Figure 9.1, school B has much lower integration than the other three, and school D has the highest mean integration of the four (although only marginally). Schools A, C and D are very similar, with considerable overlap in the distribution of the integration within the buildings. School B has particularly low integration, with no points reaching the mean integration of the other three.

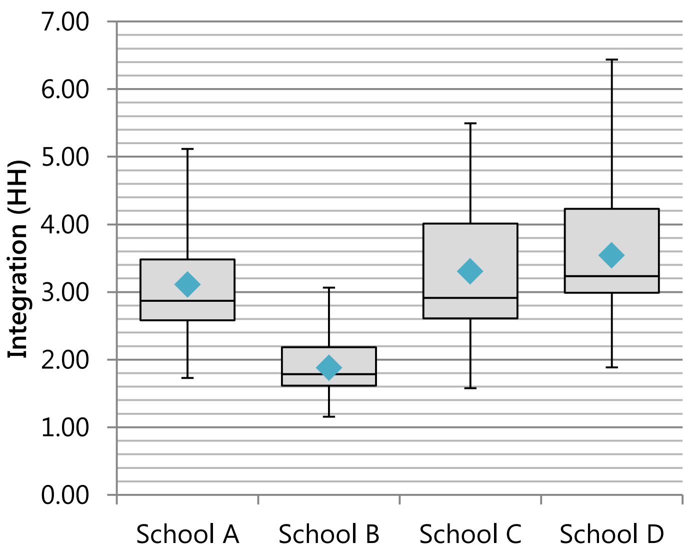



**Figure 9.1 – Box and whisker plot showing the distribution of the integration (HH) within each school**

Looking at the graph of school B, in Figure 9.3, it is clear that the ground and first floor are the best integrated areas, with the other floors significantly lower. The integration for the fourth floor is considerably lower than the ground floor, with a mean of 2.172 for the ground floor versus 1.253 for the fourth floor (shown in Table 7.1). The clear and wide circulation at School D has a clear impact on both floors (see Table 7.2), with high integration on the first floor compared to the other three schools.

**Table 9.1 – Results of the integration analysis for each school, separated out by floor**

| Floor | School A | School B | School C | School D |
|---|---|---|---|---|
| -1 | - | 1.775 | - | - |
| 0 | 3.421 | 2.172 | 3.670 | 3.810 |
| 1 | 2.752 | 2.025 | 2.702 | 3.249 |
| 2 | - | 1.655 | - | - |
| 3 | - | 1.484 | - | - |
| 4 | - | 1.253 | - | - |
| ***Overall Mean*** | ***3.109*** | ***1.876*** | ***3.303*** | ***3.543*** |

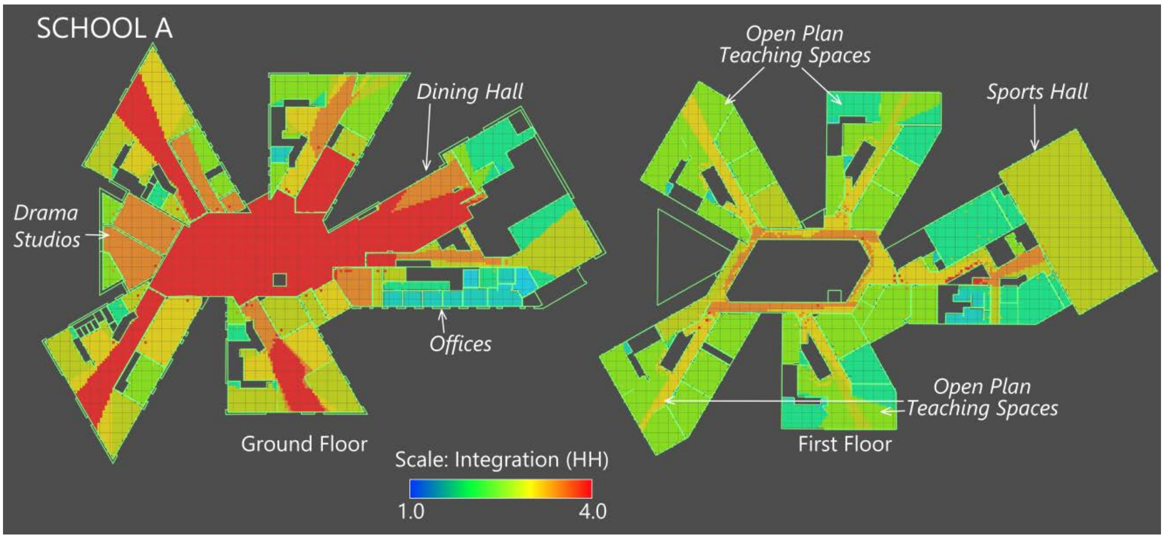



**Figure 9.2 – VGA results of School A, showing the variations in visual integration (HH) across the building**

School A, shown in Figure 9.2, is dominated by the central atrium which acts both as a space for socialising and as an important link in the circulation. Within school C (shown in Figure 9.4), the central courtyard allows access between the teaching wings on the ground floor, acting as a much larger, open-air version of the atrium in School A. School D has the highest integration of the four schools, both on average and as a point (a point on the ground floor between the circulation and the dining hall). This high integration is a consequence of the long, wide circulation spine running the length of the building (see Table 9.2), efficiently connecting the teaching wings to the rest of the building.


**Figure 9.3 – VGA results of School B, showing the variations in visual integration (HH) across the building**

**Table 9.2 – Typical corridor widths for each school, for both the ground and upper floors. Note School C ground floor circulation is a mix of open plan circulation in teaching wings or the courtyard so no dimension has been given.**

| | Typical Corridor Width (m) | |
|---|---|---|
| | Ground Floor | Upper Floors |
| School A | 3.5 | 2.8 |
| School B | 4.4 | 2.3 |
| School C | - | 2.5 |
| School D | 3.2 | 2.7 |

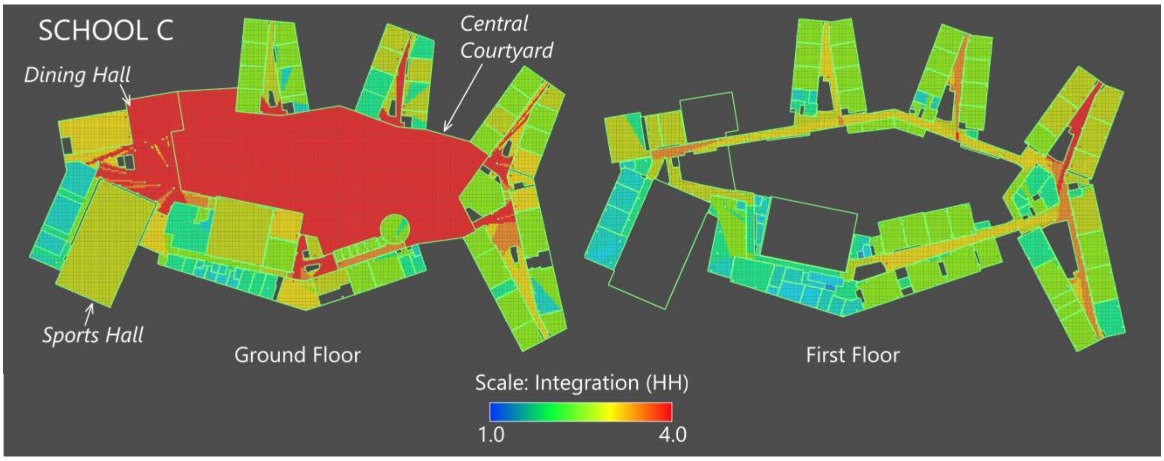



**Figure 9.4 – VGA results of School C, showing the variations in visual integration (HH) across the building**

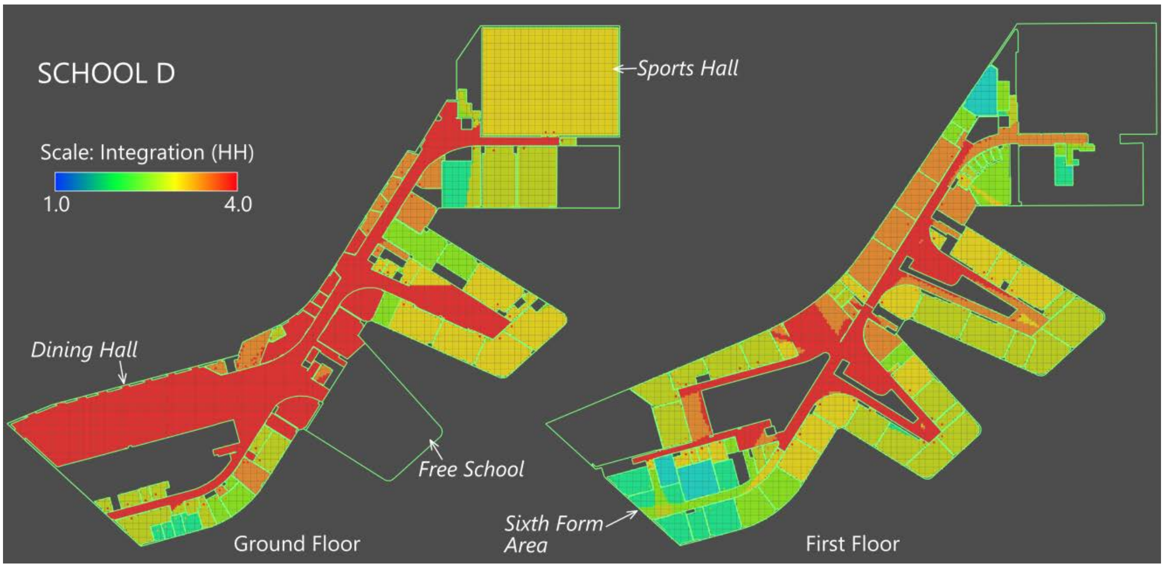


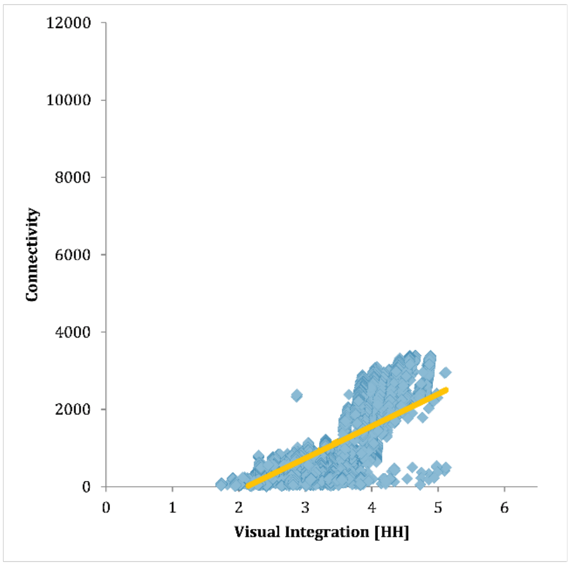

**Figure 9.5 – VGA results of School D, showing the variations in visual integration (HH) across the building**

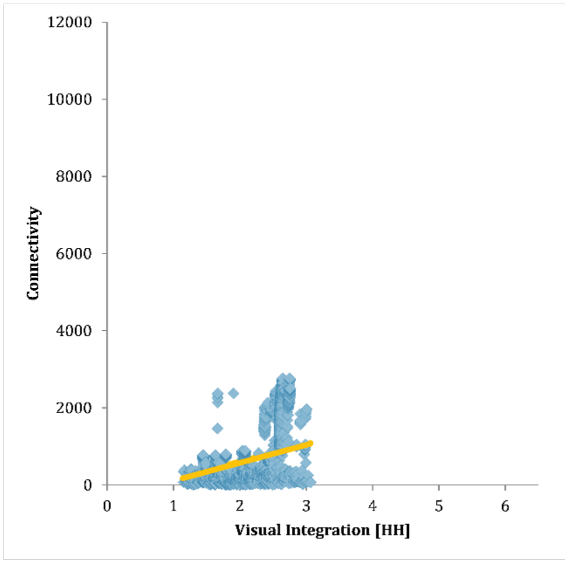
## 9.2 Intelligibility of buildings

Comparing the integration of the four schools with the connectivity produced by DepthMapX, it has been possible to determine the global intelligibility of the buildings measuring the uniqueness of the layout that assists with wayfinding. School A, with its central atrium, show a modest intelligibility of 0.379 (see Figure 9.6), with generally low connectivity of less than 4000. The low standard error (6.3) shows that the building is largely homogenous, with the wide circulation into each of the teaching wings from the main atrium assisting the intelligibility (corridor widths are shown in Table 9.2).

School B has a very low intelligibility of 0.072, with both low connectivity (less than 3000) and low integration (typically less than 3.0). The low intelligibility suggests that well integrated spaces do not occur in the well-connected spots, with the larger open spaces in the basement, away from the centre of the building. The areas of higher integration on the upper floors are not as well connected due to the narrower corridors despite them being integral to the movement through the building.

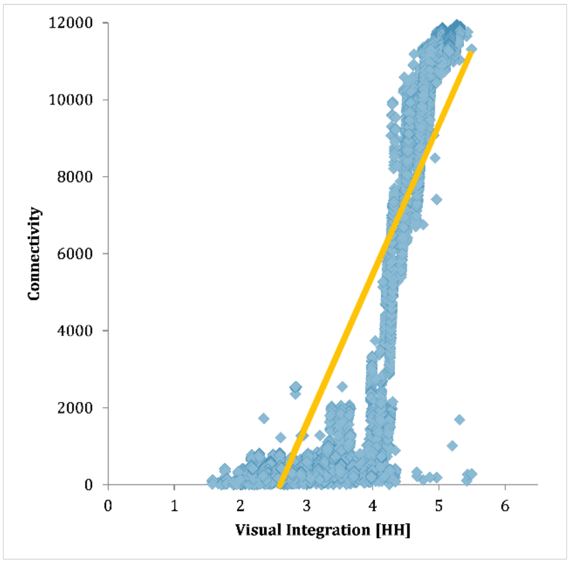
School C has a very high intelligibility score of 0.817, characterised by areas of extreme low or high connectivity (Figure 9.6) The areas within the central courtyard, which are integral to the movement of the students have both high integration and high connectivity, whereas the teaching wings have relatively low connectivity and integration. The ability of the courtyard to quickly transport students between each teaching wing is the key enabler of the high intelligibility.

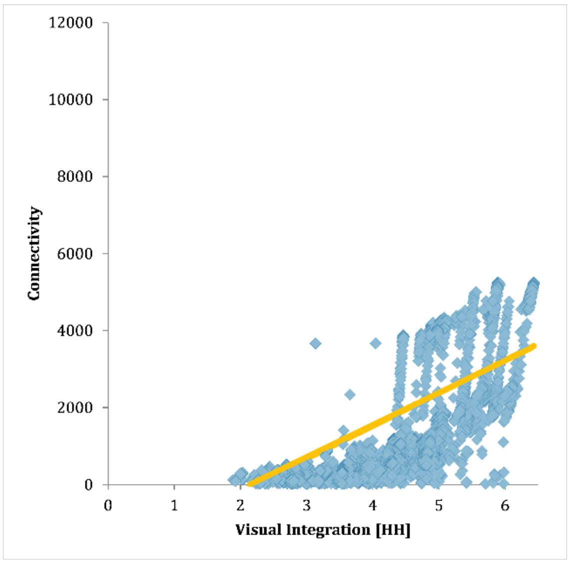



| Dependent variable: Connectivity | | | | | |
|---|---|---|---|---|---|
| *Dependent Mean:* | 861 | $R^2$: | 0.379 | *p-value:* | <.0001 |
| Parameter Estimates | | | | | |
| *Ind. Var* | *DF* | *Beta* | *St. Err.* | *t-value* | *p-value* |
| Visual Integration [HH] | 1 | 818.8 | 6.3 | 129.5 | <.0001 |

| Dependent variable: Connectivity | | | | | |
|---|---|---|---|---|---|
| *Dependent Mean:* | 553 | $R^2$: | 0.072 | *p-value:* | <.0001 |
| Parameter Estimates | | | | | |
| *Ind. Var* | *DF* | *Beta* | *St. Err.* | *t-value* | *p-value* |
| Visual Integration [HH] | 1 | 452.1 | 8.4 | 53.7 | <.0001 |




| Dependent variable: Connectivity | | | | | |
|---|---|---|---|---|---|
| *Dependent Mean:* | 2772 | $R^2$: | 0.817 | *p-value:* | <.0001 |
| Parameter Estimates | | | | | |
| *Ind. Var* | *DF* | *Beta* | *St. Err.* | *t-value* | *p-value* |
| Visual Integration [HH] | 1 | 3877.2 | 7.6 | 509.0 | <.0001 |

| Dependent variable: Connectivity | | | | | |
|---|---|---|---|---|---|
| *Dependent Mean:* | 1133 | $R^2$: | 0.260 | *p-value:* | <.0001 |
| Parameter Estimates | | | | | |
| *Ind. Var* | *DF* | *Beta* | *St. Err.* | *t-value* | *p-value* |
| Visual Integration [HH] | 1 | 853.6 | 7.4 | 115.2 | <.0001 |

**Figure 9.6 – Global intelligibility results for School A (top left), School B (top right), School C (bottom left) and School D (bottom right)**

From Figure 9.6, it can be seen that School D has an intelligibility score of 0.260, lower than both Schools A and C, both of which have the same number of floors. However, both School A and C have a central atrium/courtyard that enables direct movement across the building, without negotiating a long corridor. The relatively wide main corridor at School D on both floors helps the visual connection between the ends of the school, but the increased length of the school detracts from its potential intelligibility.

The low intelligibility of school B suggests that the students within the school will initially struggle to comprehend the building layout (Penn, 2001), particularly compared to the school C which has a much higher intelligibility than the others in the study, but also all those found by Pasalar (2004). School A and D both have higher intelligibility than the two-storey school studied by Pasalar (2004), showing the importance of the clear circulation at both schools, and the links formed by the central atrium within school A.

## 9.3 Mean depth

As is expected, the resulting mean depth of the four schools, shown in Figure 9.7 and Table 9.3, follows a similar pattern to the integration, with school B clearly different to the other three schools, with a much higher mean depth. Schools A, C and D have similar results, with the mean average mean depth around 5 for each school (5.081, 5.361, and 4.760 respectively), much lower than the average for school B of 8.014. Schools A and D have similar standard deviations (SD 0.83 and 0.87 respectively), lower than school C (SD: 1.19) and much lower than school B (SD 1.52). Schools A, C and D clearly require fewer visual steps to traverse on average than school B, likely caused by the large difference in building floors, i.e. two compared to five. School B also has much narrower circulation compared to the other three schools, which are all based on teaching blocks arranged from a central circulation of some form. This would indicate that at school B the mutual visibility of the spaces is much lower than the other schools, and that movement will be more convoluted, reducing chances for interaction between students as they move through the school.

From Figure 9.8, it can be seen that School A has a clear area of low mean depth within the central atrium on the ground floor, with low mean depth also visible on the main circulation routes into each of the teaching wings. This would indicate an area where students would frequently pass each other between lessons and breaks. The spaces on the first floor, both circulation and rooms, have a lower mean depth than comparable spaces on the ground floor, likely caused by the increase in movement afforded by the central atrium between the teaching wings. The open plan teaching spaces have similar levels of mean depth to other teaching spaces within close proximity, indicating that although the teaching spaces have no walls, they may not be better integrated.

**Table 9.3 – Results of the mean depth for each school, separated by each floor**

| Floor | School A | School B | School C | School D |
|---|---|---|---|---|
| -1 | - | 8.233 | - | - |
| 0 | 4.737 | 6.957 | 4.699 | 4.491 |
| 1 | 5.474 | 7.351 | 6.023 | 5.055 |
| 2 | - | 8.752 | - | - |
| 3 | - | 9.562 | - | - |
| 4 | - | 11.108 | - | - |
| ***Overall Mean*** | ***5.081*** | ***8.014*** | ***5.361*** | ***4.760*** |

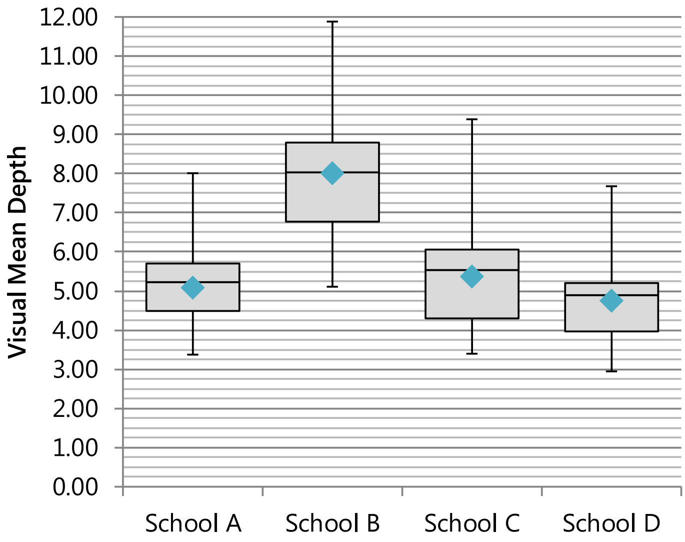



**Figure 9.7 – Box and whisker plot showing the distribution of the mean depth for each school**

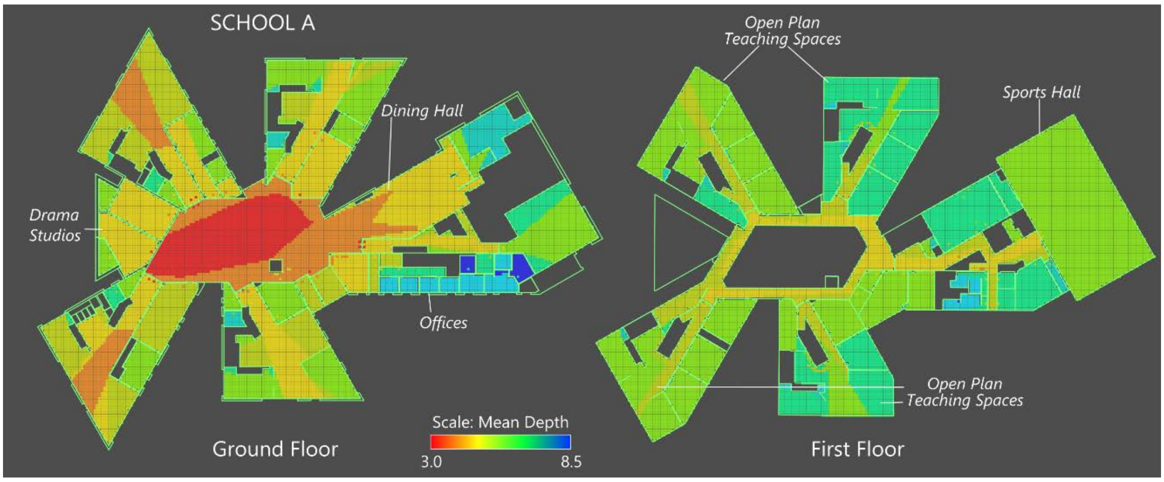



**Figure 9.8 – VGA results of school A, showing the mean depth**

The VGA for school B, shown in Figure 9.9, highlights that the mean depth increases for each floor as it moves away from the ground floor, with all the fourth floor mean 11.108 (Table 9.3). As with the school A, the increased connectivity created by the large area on the ground floor, in this case the dining area, is dominant in enabling visibility, but as the spaces become more distant the effect of this space becomes less of a driver. Also distinct within Figure 9.9 is the lack of clarity of the circulation, with the tight and twisting route on the upper floors and variety of routes through the building making chances for interaction reduced away from the ground floor (see Table 9.2 for comparative corridor widths).


**Figure 9.9 – VGA results of school B, showing the mean depth**

The mean depth graph for school C, shown in Figure 9.10, has a clear area of low mean depth in the central courtyard, with the direct link between each teaching wing clearly enabling a reduced number of visual steps to see the whole building. The first floor internal circulation has a low mean depth caused by the long straight runs and the small atria in each teaching wing. The sports hall has a lower mean depth than many of the teaching spaces, with its location close to the dining hall and central courtyard creating greater visual connectivity. Many of the teaching spaces have higher mean depths than in either school A or D, indicating that although the teaching wings are easily accessible, the rooms themselves are less so, likely because of the small atria and narrow circulation in the teaching wings.

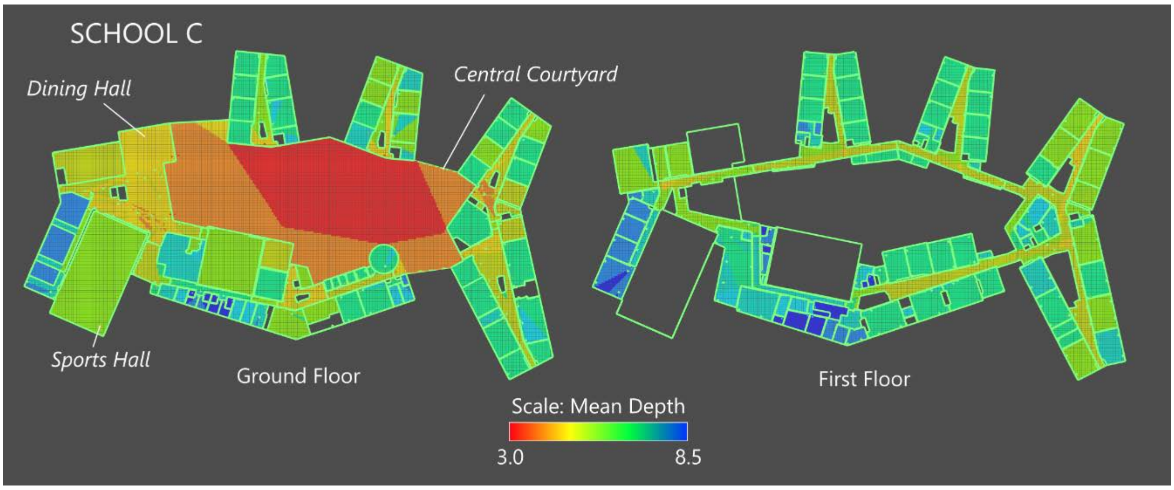



**Figure 9.10 – VGA results of school C, showing the mean depth**

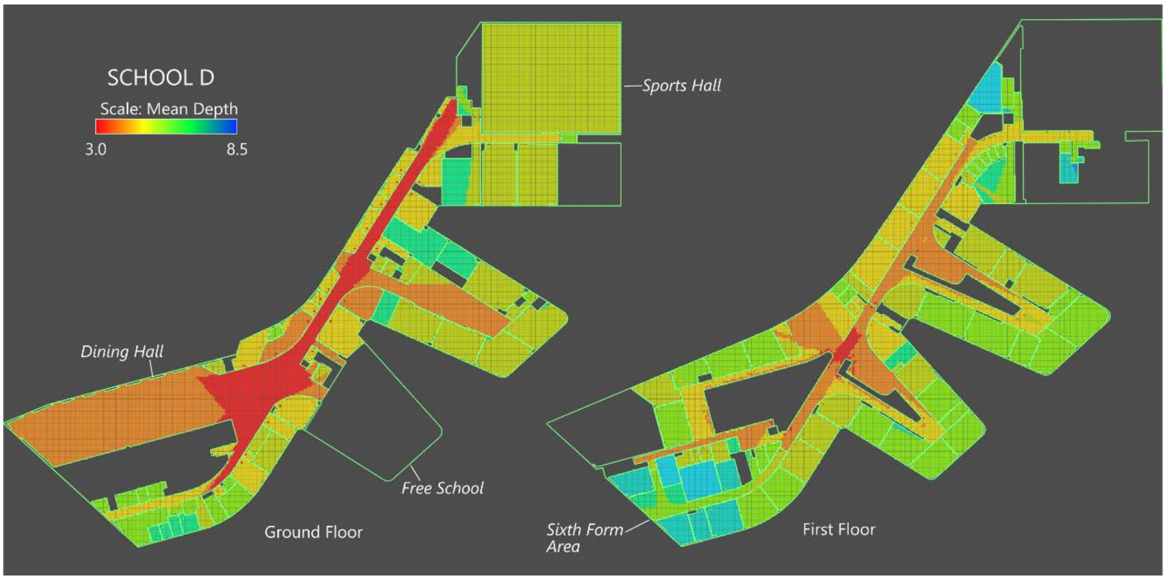



**Figure 9.11 – VGA results of school D, showing the mean depth**

Unlike schools A and C, the mean depth of school D is dominated by the large central corridor on the ground floor, linking the large dining hall with the sport hall (see Figure 9.11). Each of the teaching wings, on both floors, have low mean depth reflecting their relative closeness to this central spine. One notable exception is the sixth form area, where the mean depth noticeably increases, caused by the indirect links to the rest of the building. Each of the teaching rooms outside of the sixth form centre has low mean depth. Note that a free school occupies the ground floor of one teaching wing and has been omitted from this study as it is an entirely separate organisation. The area occupied by this free school would be a very highly connected area within the school, originally built as an open plan teaching area for the new year 7 students.

## 9.4 Summary

With the analysis, it would be expected that the initial movement of students within School B would be expected to be less direct than the other three schools, with School C the simplest and School A marginally simpler than School D. A summary of the overall results from the space syntax analysis are shown in Table 9.4.

**Table 9.4 – Summary of space syntax measures for each building**

| | School A | School B | School C | School D |
|---|---|---|---|---|
| Mean Integration | 3.109 | 1.876 | 3.303 | 3.543 |
| Intelligibility | 0.379 | 0.072 | 0.817 | 0.260 |
| Mean Depth | 5.080 | 8.020 | 5.360 | 4.760 |

*The number of floors and circulation routes directness significantly impact intelligibility and space measures.*

With the integration, intelligibility and the visual step depth results, School B clearly has a significantly different configuration to the other three schools, with each measure identifying the building as likely more difficult to navigate. The intelligibility of School C ($R^2$: 0.072) is 3.6 times less than the next lowest value for School D ($R^2$: 0.260). Within School B, the tight, short corridors and the number of routes through the building gives rise to the decreased intelligibility, which is lower than the four storey building studied by Pasalar (2004) that had an intelligibility $R^2$ of 0.172. The reduced footprint of the higher floors reduces the effect of the additional storeys on the overall visibility scores. Notably within School B, there are recognised issues with student movement through the school, necessitating one-way systems to prevent excessive congestion during breaks and in-between lessons, indicating that the space syntax results may be an accurate reflection of the actual student movement.

*A central courtyard creates a highly connected building form.*

Schools A, C and D are relatively similar when comparing the integration or the visual step depth, with School C having a greater spread of both integration and step depth than the other two schools. However, comparing the intelligibility of each school, School C is shown to have a considerably higher score ($R^2$: 0.817) than School A ($R^2$: 0.379) or School D ($R^2$: 0.260). School C is more intelligible than any of the schools studied by Pasalar (2004), even the single storey school ($R^2$: 0.577). This high intelligibility is caused by the high connectivity afforded by the central atrium, creating short routes between each teaching wing. School D has a notably lower intelligibility than the integration or visual step depth would indicate, with the long corridor form reducing the score compared to the central atrium form seen in School A.

# 10 Methodology – Environmental Performance and Perception

The ISAT has been created to collect open ended feedback from the occupants of a building, but it forms only one part of the multi-method analysis presented within this work. To gain a fuller picture of the schools and their buildings, more traditional techniques have been applied; questionnaires and environmental monitoring. By combining the questionnaire and the ISAT it is possible to gain a fuller vision of the student perceptions, which will be quantified through using the environmental measures. This chapter will outline the environmental monitoring undertaken in the four schools, followed by describing the bespoke questionnaire and its completion by the students.

## 10.1 Environmental Monitoring

The perspectives of the occupants provide a valuable insight into the built environment, but the personal nature of these perspectives can make them obtuse if the environment they were formed within is not understood. As such, a key element of the low level case studies is to measure the environment within the four schools, quantifying the environmental aspects to illuminate the responses. The review into the impact of the built environment of schools found that there are four key environmental factors to measure:

- Indoor Air Quality (IAQ)
- Acoustics/noise
- Thermal Comfort
- Daylight

Each of these environmental factors has many facets that could be measured, but within this study only those aspects that have been shown to have a link with students' performance will be captured.

### 10.1.1 Measuring indoor air quality and temperature

With the focus of this work on student perception and performance, not the health of the students, the following aspects of IAQ were identified as having a link with the cognitive performance of the students (with relevant literature in brackets):

- $CO_2$ (Bakó-Biró et al., 2012; Coley et al., 2007; Myhrvold et al., 1996; Shaughnessy et al., 2006; Shendell et al., 2004)
- Temperature (Wargocki & Wyon, 2007; Wong & Khoo, 2003)
- VOCs (Otto et al., 1992)
- Particulates (Mattsson & Hygge, 2005)
- $NO_2$ (Pilotto et al., 1997)

While other aspects of the IAQ have been shown to be important to the health of the occupants (notably ozone and formaldehyde) these have not been included. Each aspect of the IAQ requires a different measurement approach as outlined in Table 10.1.

Measuring $CO_2$ within the teaching spaces is clearly necessary given the strong links between the $CO_2$ concentrations and the cognitive performance in previous research and potential for new schools to have high $CO_2$ concentrations (Mumovic et al., 2009). Within each monitored classroom the $CO_2$ concentrations were measured using an Eltek GD47 sensor, with a non-dispersive, infrared type, conforming to BS EN ISO 16000-26:2012, complete with automatic, daily self-calibration to ensure accuracy over prolonged periods. This unit also provided temperature measurement with a sensor that conformed to the standards set out in BS EN ISO 7726:2001.

With Otto et al. (1992) finding some links between cognition and VOC concentrations, but Mendell and Heath (2005) finding no clear relationship, this work provides an opportunity to examine any potential link further. VOCs are not one chemical compound, but many and this necessitates the use of the total volatile organic compounds (TVOCs) metric in a holistic study such as this. This aggregates the total quantity of VOCs within the sampled air, providing the ability to link any overall links between concentrations and learning, but does not identify any specific chemical compound. TVOCs were recorded using a Tiger PhoCheck active sampler using a 10.6 eV ionisation lamp. This unit pulls air across the ioniser and measures the potential difference caused by the lamp, inferring the amount of TVOCs in the air.

**Table 10.1 – List of equipment and relevant guidance for environmental monitoring**

| Monitored parameters | Method | Duration of measurements | Intervals | Accuracy/detection limit | Equipment/Analysis | Standards/ publications |
|---|---|---|---|---|---|---|
| Temperature (°C) | Rotronic sensor | Five working days | 1 min | ±0.5°C (range: −30°C to 65°C) ±1.5% | Eltek GD47 | BS EN ISO 7726:2001 |
| $CO_2$ (ppm) | Non-dispersive infrared (NDIR) | Five working days | 1 min | 3% (range 0–20 000 ppm) or 50 pppm whichever is greater | Eltek GD47 | BS EN 16000-26:2012 |
| PM1, PM2.5, PM10 (μg/$m^3$) | Optical method | Five working days | 1 min | 0.1% of reading or 1.00 μg/$m^3$, whichever is greater | TSI DUSTTRAK DRX Model 8533 | |
| TVOCs (ppb) | Photo-ionisation | Five working days | 1 min | 5% (range 1 ppb – 20000 ppm) 0.10 μg/$m^3$ | Tiger PhoCheck, Ionscience | |
| $NO_2$ (μg/$m^3$) | TEA principal | 2 weeks | | 0.57 μg/$m^3$ | DIF 100 RTU, Gradko International Limited | BS EN 13528-3:2003, BS EN ISO 16000-15:2008 |
| Daylight (%) | Daylight Factor method | 1 day | | 1 lux | Testo 435 with lux probe | Littlefair, P. J. BRE IP 15/88 (Littlefair, 1988) |
| Reverberation (secs) | Impulse | 1 day | | | 3M SoundPro DL | BS EN ISO 3382-2:2008 |
| Ambient Noise (dB $L_{AEQ,5}$) | 5 minute weighted average | 5 minute period during one day | | | 3M SoundPro DL | ANC (2011) |

As with the VOCs, particulates were only shown to have a limited relationship to the cognitive performance, but this study provides an opportunity to explore any potential link further. No standards for the measuring the particulate concentrations were found, so the method used by Chatzidiakou et al. (2014) was adopted to enable comparisons with their results. Particulates were logged using the TSI DustTrak DRX unit, using laser photometry to continuously measure the particulates within the air pumped through across the sensor. Through the sensor, the particulates are able to be separated out into $PM_{10}$, $PM_{2.5}$ and $PM_1$. This unit was calibrated and zeroed prior to use to reduce sampler drift.

The concentration of $NO_2$ within the schools has been shown to have a link with absenteeism of the students (Pilotto et al., 1997), but is also very location dependent as the major source of $NO_2$is traffic. Measuring the $NO_2$ concentrations at each school will enable the effects of the different locations on the internal air quality to be exposed. Unlike the $CO_2$, TVOCs, temperature and particulates, $NO_2$ is defined by the surrounding area not the occupancy of the building, as such there is less need for time-based concentration data. Instead, a simpler passive sampler was used that absorbs the $NO_2$ at a known rate using a TEA solution. Two $NO_2$ passive samplers were installed in each space to ensure redundancy should one of the samplers fail, and left for two weeks to absorb the $NO_2$. These were analysed by Gradko International Ltd, who hold the relevant UKAS accreditation to determine the sampled concentration. Final concentrations were blind subtracted using an unused sampler from the same batch and stored at the same ambient conditions as the tubes experienced.

Within the monitored spaces, the equipment was mounted in a protective cage to prevent tampering by the students. This cage was mounted at desk height, representing the air quality for the seated students, and placed away from external walls and direct sunlight to prevent any localised effects. In addition to monitoring the internal environment, the parameters measured indoors were duplicated externally to ascertain the relative performance of the building. The active sensors were placed within IP67 cases designed to house the sensors, with the DustTrak connected to the air inlet using a PTFE tube to prevent contamination. External temperature was measured using a Vaisala WXT520 weather station, which also collected wind speed, wind direction and rain fall rates (although these weather parameters were not used). The passive $NO_2$ tubes were mounted within a Stevenson screen to prevent direct solar irradiation, but allow good airflow. All external equipment was placed on the roof, away from exhausts or soil vent pipes to prevent contamination of the equipment.

### 10.1.2 Measuring acoustic performance

Within the literature review, there were two distinct issues surrounding the acoustic environment that impact on school performance; ambient noise (noted by Shield and Dockrell (2004)) and reverberation (as discussed by Fintitzo-Hieber (1978) and Crandell and Smaldino (2000)). Aspects of these two need to be included within the study given their clear relation to the academic outcomes.

Impact noise from neighbouring spaces are an intermittent nuisance, and measuring the insulation between the spaces (using methods such as BS EN ISO 16283-1:2014 (British Standards Institution, 2012)) does not capture the noise within the room, only the propensity for noise through impact. As such, this has not been measured within this study.

To understand how each building sits within their environment, the ambient noise levels at each space compared to the external noise levels. The average noise levels were captured using the A-weighted sound-levels, as used within BB93 (DfES, 2003) and the ANC guidance, and measured for a period of 5 minutes during the school holidays. During the measurement period, no significant noise events occurred, and so the 5 minute average was deemed acceptable as an indicator of the ambient noise levels in the teaching spaces (Association of Noise Consultants, 2011, sec. 8.1). This separated the sound of the school from the site specific sounds allowing distractions from the environment to become apparent. External locations were chosen adjacent to each monitored space and monitored for the same length of time as the space to ensure compatibility. Where spaces had mechanical ventilation systems, two ambient noise level measurements were taken, one with the systems running and one without. In naturally ventilated spaces the ventilation routes were opened (windows in all the tested spaces), to best represent the operation of the room.

Reverberation has a direct impact on the space and needs to be measured. Following the procedure outlined in BS EN ISO 3382-2:2008 (British Standards Institution, 2009) and BB 93 (DfES, 2003), the reverberation was measured using the 'Engineering' precision impact method (British Standards Institution, 2009 table 1), with two microphone positions and three noise source positions, giving a total of 6 source-microphone combinations. Each space was tested when empty, as per BB 93, using a popping balloon as the noise source in three locations spaced out down the centre of the room along the longest axis of the space, as shown in Figure 10.1. The reverberation time has been defined as the average time in seconds for the noise level to drop 20 dB in the 500 Hz, 1000 Hz and 2000 Hz frequencies, averaged across all six tests (using the methodology of BB93).

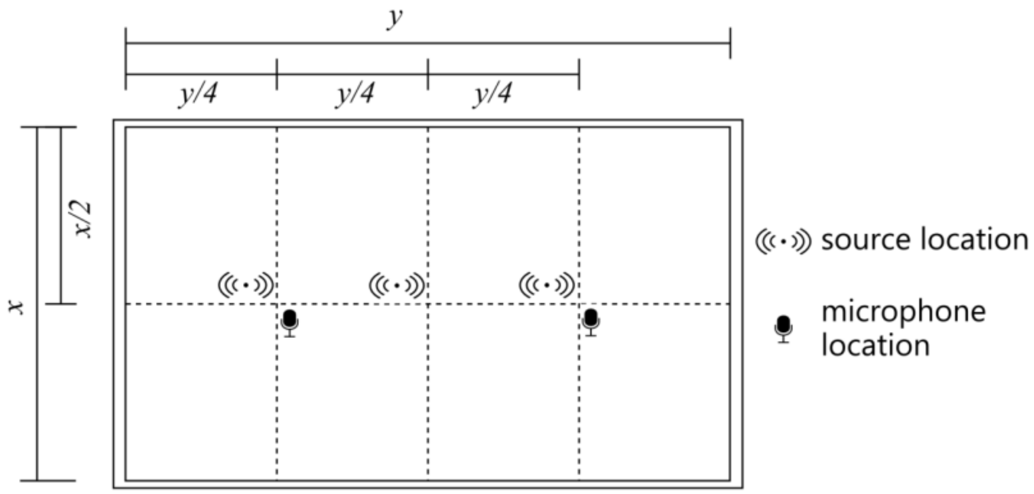



**Figure 10.1 – Indicative locations of microphone and noise sources for impulse reverberation testing, where** $y>x$

### 10.1.3 Measuring daylight

Daylight within the classroom was shown to have an impact on the student performance, notably by Heschong et al (2002), but also the proximity to the windows was also shown to have a positive effect in work places (Boubekri & Haghighat, 1993b; Yildirim et al., 2007). To capture both these elements of daylight, the daylight factor was used, as recommended within the Building Bulletin 90 (Department for Education., 1999) that provided design guidance at the time the schools were built. The daylight figure is the average percentage of the external light level that reaches the classroom at desk level (taken as 750 mm above finished floor level). The space is divided into equally spaced grid-points and the lux level taken at each point, which was then compared to the external lux level at that time. This was done during a uniformly overcast day, where there was no direct sunlight available. Within each space monitored, the blinds were closed to differing extents, but to capture the room potential, the daylight was monitored with the blinds fully open in all spaces. On an overcast day, many of the spaces were too dark with the blinds as found to generate reliable lux measurements. The daylight factor was calculated using the formula given by Littlefair (1988).

### 10.1.4 Room selection and monitoring period

In the secondary schools selected, the students move between classrooms for each lesson, unlike the relatively 'static' students usual in primary schools, where they have one room and the lessons change throughout the day (Barrett et al., 2013). This produces a problem with capturing the whole environment on such a large scale, with the sheer quantity of monitoring equipment prohibitively expensive. Instead, three representative spaces within each school were monitored, selecting the spaces based on four criteria:

- Orientation (controlling for solar gains, and daylight)
- Servicing strategy (mix of ventilation and heating strategies where more than one exist)
- End use (typical classroom or science laboratory)
- Building storey (controlling for stratification of environments)

Given that the students visit a variety of spaces, the rooms selected have to represent a broad number of characteristics. In each school, it was decided that one science laboratory and two typical classrooms would be monitored. In science laboratories, the FF&E are substantially different from the rest of the school spaces, with a focus on resilience to spills that would soon leave other spaces grubby, hence many spaces have hard floor coverings (lino for instance) and hard-wearing work-benches. Additionally, as is common in British schools, there are a number of gas outlets to use during experiments, which may have a direct impact on the air quality. As science is mandatory in all English schools, although there is some flexibility in the amount, every student in the secondary schools will experience the environment in the science laboratory. A vast majority of the other lessons revolve around a more typical teaching room (defined as a 'basic teaching spaces' in building bulletin 103), and this study has selected these room-types for the other monitored spaces.

The environment of each room in the school will change over the course of a day and also over a week, with each space responding to the occupancy demands and its specific locality. By selecting a rooms with a mix of orientations, the effect of solar gains can be somewhat mitigated, as each orientation receives differing amounts of insolation throughout the day. Similarly, as the heat within the building stratifies vertically, it is natural that the rooms towards the top of the building will be warmer than those lower down the building. As well selecting spaces representing each orientation, spaces were selected by the building storey to capture this factor. It should be noted that School D had very few teaching spaces on the ground floor that were not specialist spaces (drama, food technology or resistant materials), necessitating that each chosen space was located on the first floor. Additionally, spaces that had a significant amount of internal gains, typically PCs, were rejected as they were more likely to overheat than other spaces.

Schools C and D had differing ventilation strategies depending on the orientation of the classroom, with external noise driving the need for mechanical ventilation in some spaces. In schools C and D, rooms with each system were chosen as the complexity of the services can make maintaining the environment particularly difficult.

**Table 10.2 – Key properties of each monitored space in each school (for location of rooms in buildings see appendix B)**

| School | Room ID | Room Use | Glazing Orientation(s) | Building Storey | Ventilation System |
|---|---|---|---|---|---|
| School A | 1 | General Teaching/ open plan | NNW, WSW | 1st Floor | Mechanical |
| | 2 | Science Laboratory | ENE | Ground Floor | Mechanical |
| | 3 | General Teaching | ENE | 1st Floor | Natural |
| School B | 1 | General Teaching | WSW, SSE | 2nd Floor | Mechanical |
| | 2 | Science Laboratory | SSE, ENE | 3rd Floor | Mechanical |
| | 3 | General Teaching | WSW | 1st Floor | Mechanical |
| School C | 1 | General Teaching | SSE | Ground Floor | Mixed-mode |
| | 2 | Science Laboratory | SE, SW | 1st Floor | Natural |
| | 3 | General Teaching | ESE, NNE | 1st Floor | Natural |
| School D | 1 | General Teaching | NW | 1st Floor | Mechanical |
| | 2 | Science Laboratory | NE | 1st Floor | Natural |
| | 3 | General Teaching | SE | 1st Floor | Natural |

With the active equipment producing continuous data over the monitored period, much of the recorded data will be for unoccupied periods of the school day. To ensure that the data is relevant to the students, the data will only be used that corresponds to the periods that the students attend school. To ensure that the environmental conditions are comparable, the same occupied hours were applied to each school. From discussions with the management at each school, it was noted that there were a number of after-hours activities, mainly homework or revision clubs, that extend until 6pm, and students arrive at the school from 8am. Despite this long operating period, only one selected space within School B was used outside of the core hours. To ensure that the schools remained compatible, the core hours given in Building Bulletin 101 (DfES, 2006) were used; 9am to 3:30pm. All of the schools were designed to conform to these standards and so there is a universality to these times. All reported data, unless otherwise noted, will represent this occupied period. Note that the passive samplers are not able to differentiate the occupied hours so represent the whole study period.

## 10.2 Questionnaire

Within a school building there are two end-users; students and staff (including all administration and ancillary staff), who are both integral to the functioning of the school. This body of work is focusing on the point of view of the students, although initial plans involved consulting both staff and students. Discussions with the case study schools revealed an increased sensitivity towards the staff, feeling that the introduction of a questionnaire would increase tensions to an unacceptable point. As such, this work focused on the student perceptions of their school and the built environment. Questionnaires, such as the BUS (Arup, 2015) are not aimed at children and do not recommend their feedback as reliable, however successful feedback from students has been captured by large Europe-wide studies such SINPHONIE (Csobod et al., 2014), indicating that responses from students are accurate.

The questionnaire represents a key part of the investigation into the school and the built environment, allowing the students to feedback their opinions on their school in a controlled manner. This not only allows the capturing of their perceptions on the built environment, but also their views on the school climate, allowing links between the two areas to be analysed. Through using a questionnaire, particularly with students, the areas of interest to this research can be the focus, a *guided* approach that ensures comparability between the schools reviewed. To form a holistic view of the school, there are two predominant sections (with an occupant background preface):

1. School climate
2. Built environment

The school climate section contains questions as to how the students perceives the school operation, covering topics of connectedness, fairness, support and teacher-student relationships. The built environment covers the areas measured in each school, as noted in section 10.1, including air quality, daylight and acoustic performance. Given the target audience of students, previous experience with TSB funded work (project number: 450030), showed the importance of short questionnaires and simple questions to reduce ambiguity and improve universal understanding of the questions.

### 10.2.1 Student Climate Questionnaire

Capturing the school climate from the student perspective requires questions that cover the different aspects of the school climate. While there is little consensus on the ultimate framework defining the school climate, Zullig et al (2010) created a set of questions based on historic assessments and questionnaires, providing a practical definition of the school climate. Their work split the school climate into eight factors (as shown in Table 2.1) with the 'positive student-teacher relationship' explain the greatest variance at 27.6%.

As this questionnaire is aimed at students, considerable effort has been made to ensure that the questionnaire is no longer than necessary, preventing potential questionnaire fatigue, but also enabling the questionnaire to be completed in under 15 minutes as required by the schools. As such, the full set of questions defined by Zullig et al could not be used, with a reduced set produced instead. The questions concerning the 'school physical environment' were removed as these duplicated the questions developed within the built environment section but with less detail than required to compare the responses to the measured environment. Within each of the remaining seven factors defined by Zullig et al, the questions that had components over 0.7 were included in the questionnaire generating a list of 14 questions that capture the school climate.

Each of the school climate questions were formatted as 5-point Likert style questions, with responses from 'Strongly disagree' to 'Neutral' to 'Strongly agree'. This was chosen over a 7-point scale to reduce the ambiguity of the two intermediate levels between neutral and strongly agree or disagree, increasing comparability between students and schools. All questions were phrased as positive sentiments to enable the questionnaire to be more intelligible and thus simpler to complete, except question 14 relating to perceived exclusion/privilege[21] where the wording has been kept the same to ensure the principles of Zullig et al remain the same, but during analysis requires careful handling to ensure the negative basis is maintained.

In addition to the 14 questions set out by Zullig et al. an overall school climate question was added to capture the overall pervasive attitude towards the school. This enables the individual components of the school climate to be compared to the overall perception. The final questionnaire can be seen in Appendix C.

### 10.2.2 Environmental Section

The environmental section of the questionnaire needs to capture not only the student opinions on their built environment, but also enable comparisons with the questionnaire, space syntax and the Interactive Space Analysis Tool. From the literature review, the following aspects of the built environment were identified as necessary to include in the questionnaire, with the additional measurements within the study identified in brackets:

- Building aesthetics (ISAT)
- Cleanliness/maintenance (ISAT)
- Movement through the building (space syntax)
- Winter comfort: temperature and air quality (environmental measurements)
- Summer comfort: temperature and air quality (ISAT)
- Acoustics/noise (environmental measurements)
- Daylight (environmental measurements)
- Overall satisfaction (not tested)

Questions relating to the summer temperature were included despite the environmental measures not covering this period to allow analysis with a broader range of comments that may be generated by the ISAT. The inclusion of year round environmental aspects also allows the

[21] The only negative school climate question is "At my school, the same person always get chosen every time to take part in after-school or special activities".

questionnaire to be re-used by other studies should. As with the school climate, an additional set of questions have been added to capture the overall performance of the built environment in winter, summer and throughout the year. The final question relates to the overall school, thinking about the school climate and the building to attempt to give a true overview of the whole school.

Matching the format of the school climate section, the questions for the built environment were based on a 5-point Likert scale, however to succinctly capture the opinions on the various aspects of the environment, not all questions used the 'strongly disagree' to 'strongly agree' wording. Building on previous work within the TSB BPE program (project number 450030) and the successful Building Use Survey (Arup, 2015), different scales were applied to make the questions more appropriate for the end use. Questions relating to aesthetics, cleanliness/maintenance, movement and overall opinions were phrased as standard 5-point Likert scale questions, using the same scale as school climate questionnaire. For the winter and summer temperature questions, the wording was changed to "*how is the temperature*", with the scale running from "*Too cold*" to "*Perfect*" to *"Too hot"* as shown in Figure 10.2. Using this scale negates the need for the three typical Likert-style questions to determine the same information[22]. Similarly, the questions for the amount of daylight followed the same convention, using "*Too little*" to "*Too much*", with two questions asked, one for the classrooms and one for the rest of the building. Within the environmental monitoring, only daylight within the teaching spaces is being monitored and this separation ensures that there are no effects from additional spaces where the students may spend time (break out areas, canteens etc.). In each season, two questions were asked to determine how the students perceive the air quality in each season, with one focusing on *freshness*, and one focusing on *smells*. This distinction between smells and a more general feeling of freshness will enable the air quality has been used within the BUS survey and encourages the respondent to think about the different aspects of the air quality.

[22] To capture the same information, the respondent would need to ask whether they agree the temperature is perfect, whether the temperature is too cold, and whether the temperature is too hot. Strongly disagreeing to just one of those questions does not provide enough information to determine whether the student feels to hot or cold in that season.

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | Perfect | | | |
| In *winter*, how is the temperature: | Too cold O | O | O | O | O Too hot |
| | | | Neutral | | | |
| In *winter*, how is the air in the rooms: | Stuffy O | O | O | O | O Fresh |
| | | | Neutral | | | |
| In *winter*, how is the air in the rooms: | Smelly O | O | O | O | O Odourless |

**Figure 10.2 – Extract from the student questionnaire showing the changing scale used to capture the comfort aspects of the school (note the full questionnaire can be found in Appendix C)**

Capturing the perceptions of noise within the school focused on the issue of distractions from different noise sources; other internal areas, outside, and noises within the room. Reverberation was not included within the questionnaire as this was felt too difficult for the students to understand and it predominantly affects the teachers who need to address the whole room more regularly. The questions on noise are a four-point scale, with the headings representing the frequency of distractions from the noise source; frequently, occasionally, rarely, and never. This was used during the TSB BPE programme and enabled the students to easily determine the influence of the noise in their school.

### 10.2.3 Questionnaire Distribution

To enable a robust estimation of the environment and climate at each school, the student questionnaire targeted 25% of all students, across each year. By capturing students from each year it provides the opportunity to establish whether the overall attitude to the school changes with age and familiarity. Through discussions with the schools, the least invasive method of distribution to the students was during their tutorial time, a period reserved for general student admin that sits outside lessons. Each school included in the study had sub-divided the school into between 4 and 6 organisational groups, serving as natural breaks to target a minimum of 25% of the school. School A, B, and D had four groups, and so one group within each school was targeted with questionnaires. School C, due in part to its size, had six groups, requiring 2 groups to be subject to the questionnaire.

The questionnaires were distributed by the schools through the tutors for each class, with the tutors providing support for the students. This distribution method meant the length and simplicity of the questionnaire was particularly important, with limited time available in the tutorial and no researcher on hand to answer questions directly. As such, the number of questions was carefully balanced with the staff of the school, following a previous pilot study, with the questionnaire taking no longer than 15 minutes.

As the questionnaire is looking at the internal environment over the whole school year, the time of distribution is less important than in purely experiential research (such as (Chatzidiakou et al. 2014)). However, it is still important the questionnaires are completed at a similar time of the year to ensure that the distance from previous seasons is similar and the memory is comparably recent between all respondents. Despite attempts to ensure the questionnaire was distributed at a similar time, delays between the schools meant the questionnaires were distributed at different time of the year; December 2013 (school A), February 2014 (School B), and April 2014 (Schools C and D). All the questionnaires were completed during the heating period, lasting up until the end of April, ensuring that the students were still in a similar frame of mind when answering the questions, but there is varying distance from the summer season.

Within School D, there was growing concern over the school climate section of the questionnaire, with the school believing that the questions will raise issues with the students that they were not able to cope with at that time. At the insistence of the school, the entire school climate section was removed, preventing the analysis of the school climate for that school within the questionnaire.

### 10.2.4 Analysis

Within the questionnaire analysis, the purpose is to explore the link between the school climate and the school built environment. While there have been few works exploring both these factors of schools, studies examining each part of the school (climate or environment) are numerous (see section 2.2). Within the studies that compare the qualitative and quantities aspects, there are two predominant methods; factor analysis (or a derivative), and multilevel-modelling. Multilevel modelling is less widely used, likely due to the complexity of the models required for analysis of questionnaires (a multinomial, logistic regression being required (Rasbash, Charlton, Browne, Healy, & Cameron, 2014). The additional time taken to complete a multilevel analysis and the relative difficulty of interpreting the results is not necessary at this stage of the work, particularly given the exploratory nature. Instead, principal component analysis was undertaken, a subset of factor analysis, as it allows quick and intuitive understanding of a large dataset (although multilevel modelling is applied later in this research).

All received questionnaire data was inputted into MS Excel, with the multiple choice results coded from 1 to 5 (or 4 in the case of acoustics questions). Prior to the analysis of the dataset, the results were normalised to between 1 and -1, with 1 representing a positive response and -1 necessarily negative. This is particularly important where the questions have differing polarity (statements are either negative or positive) or differing lengths to ensure the component analysis interprets each question equally. This is straightforward for questions on the 5-point Likert type scale with the central result (coded as a '3') corresponding to neutral, and the extremes varying from positive to negative. However, to reduce the length of the questionnaire a number of the environmental aspects (namely the comfort, daylight and acoustics) have different scales. Table 10.3 shows how the raw inputted values are normalised to enable the analysis. Note that for the questions that have perfect in the middle of the range and negatives on each extreme, the central value (3) was normalised to 1, and any other response a negative attribute.

**Table 10.3 – The inputted values from the questionnaires and the normalised values used in the components analysis for three indicative questions**

| | | **Inputted Value** | | | | |
|---|---|---|---|---|---|---|
| | | **1** | **2** | **3** | **4** | **5** |
| **Outputted Values for each question** | My school is neat and clean | *-1.0* | *-0.5* | *0.0* | *0.5* | *1.0* |
| | In winter, how is temperature? | *-1.0* | *-0.5* | *1.0* | *-0.5* | *-1.0* |
| | How often are you distracted by noise from outside? | *-1.0* | *-0.33* | *0.33* | *1.0* | *N/a* |

The normalised data was analysed using SAS 9.3, a statistical package that contains a factor analysis procedure, *PROC FACTOR* (SAS Institute Inc., 2013). The procedure first shows the simple correlation between variables, with Kaiser's Measure of Sampling Adequacy (MSA) used to ensure that the variables are not correlated. Once the final set of variables had been decided based on the MSA values, the number of principal components will be decided, as there will be as many factors as variables. There are a number of methods for choosing the number of factors to take forward, but the predominant two recommended by Field and Miles (2010)are:

- Use all components with eigenvalues over 1.0 (Kaiser-Guttman rule from Jackson (1993))

- Use of a scree plot to find the point of inflexion, and keep all factors to the left of that point

The rule for using components over ‘1’ is somewhat arbitrary, although it is true that the components kept will have a strong relation to the dataset, and by including more components the importance of the components is diluted. This can make finding the underlying pattern considerably harder, as such for this study a scree plot will be used to identify the number components to keep.

Adding importance to the components to clarify underlying trends in the data can be accomplished by rotating the eigenvectors to better represent the data. Rotating the vectors can be undertaken in two predominant methods: orthogonal and oblique. Mathematically, orthogonal rotation keeps the eigenvectors perpendicular (in however many dimensions the data is represented), whereas oblique rotation allows each eigenvector to rotate independently. Orthogonal rotation should only be undertaken when the data in each variable is independent, whereas oblique rotation can be used when the data is dependent (Field & Miles, 2010). For this data, where we are dealing with people and thus each component is likely to be related to others, oblique rotation was used, in particular SAS’ *OBLIMIN* rotation method with default rotation weight (see (SAS Institute Inc., 2013)). Once the rotated factors have been collected for each variable, the underlying theme behind each factor can be drawn out, highlighting the connection between the variables measured.

# 11 Results – Environmental Performance and Perception

Using the methodology outlined in section 8, four secondary schools were holistically evaluated, capturing the whole school environment. This chapter first introduces the environmental measurements found, followed by the results of the questionnaire and finally statistically comparing the two using multilevel modelling.

## 11.1 Environmental Monitoring

The environmental monitoring of the case study schools generated data that described the school environment in three classrooms for a one-week period. The data for each of these environmental measures from the occupied period of 9am to 3:30pm is analysed in the following sections.

### 11.1.1 Indoor Air Quality and Temperature

Over the measured week at each school, the mean temperature during occupied hours at each school was between 21°C and 24°C, as shown in Figure 11.1, despite the wide range of external temperatures experienced, particularly at School C. Only School D experienced any temperatures over 28°C, the temperature limit prescribed by Building Bulletin 101 (DfES, 2006), but this occurred as a sharp rise as the end of the school day occurred (rising to 31°C from 22°C), suggesting that this was due to tampering with equipment rather than true air temperature. Also visible from Figure 11.1 is that few temperatures were experienced below 20°C at any school (with the lowest temperature at School B of 18.4°C), suggesting that the optimum temperatures suggested by Wargocki and Wyon (2007) of 20-27°C were met. During the study period the heating at all four schools was switched off, with the warm internal temperatures showing the influence of the thermally tight fabric and the high density of heat gains in the monitored classrooms (the students).

Within Figure 11.2 the internal $CO_2$ levels show that school A, B and D all rarely reached the top limit of 1,000 ppm suggested by Building Bulletin 101 (DfES, 2006), with school C occasionally reaching this concentration. Within school C, the teaching rooms were noticeably stuffy at the end of each day, reaching concentrations as high as 4,188 ppm during the teaching day. Within these spaces there were manually operated windows, however the teachers did not want to open them due to the cooler weather creating drafts.

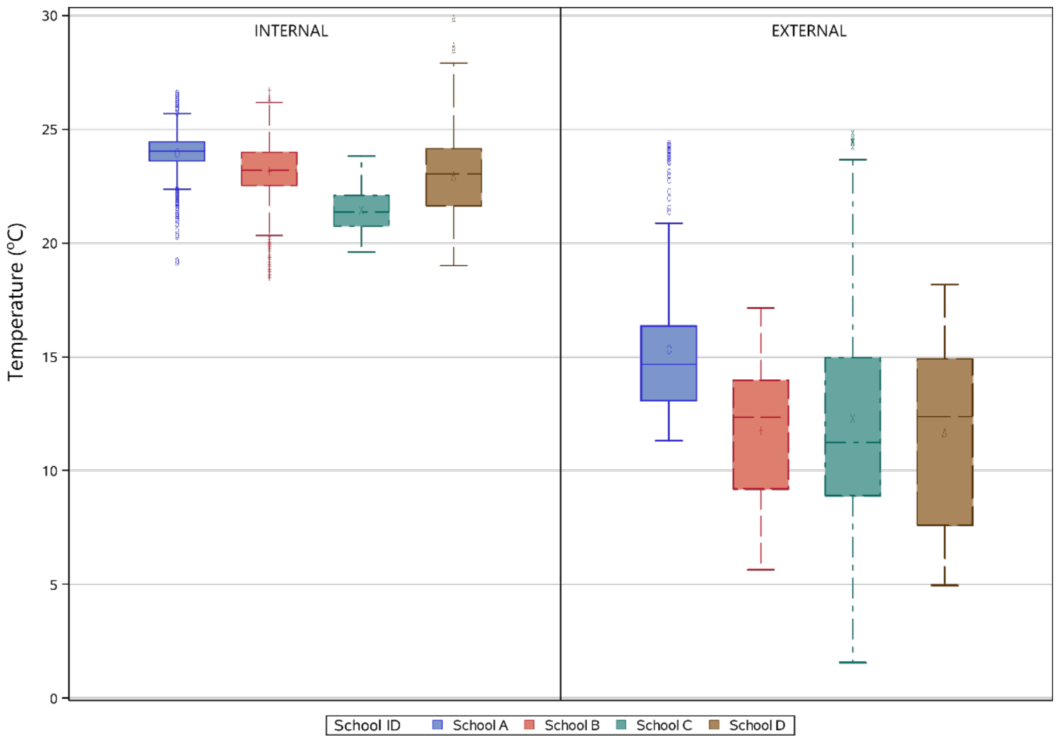



**Figure 11.1 – Internal and external measured temperatures at each school during occupied hours**

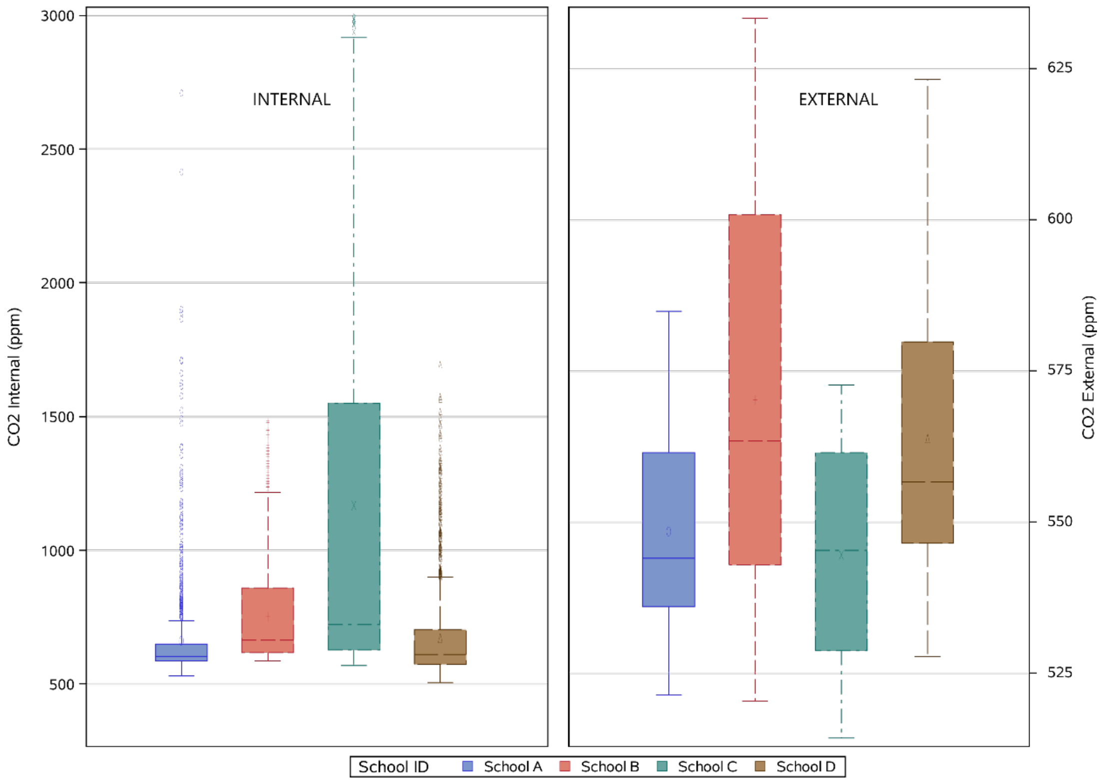



**Figure 11.2 – Internal and external measured $CO_2$ concentrations at each school during occupied hours**

The other three schools had very low concentrations, notably lower than those found by Mumovic (Mumovic et al., 2009) in their study of schools, with mean concentration all below 800 ppm (School A: 663 ppm, School C: 755 ppm, and School D: 674 ppm), compared to School C with a mean concentration of 1,176 ppm. School A benefits from the large spaces examined, with one space a large open plan area able to diffuse any $CO_2$ prior to build up, and the science space also a large classroom. Schools B is fully mechanical ventilated, although small opening windows are provided, which was re-commissioned in the weeks prior to the study, showing the potential of mechanical system. Within School D, mechanically ventilated room 1 had much higher peaks of $CO_2$ concentration (maximum 1,710 ppm) than rooms 2 or 3 (maximum 1,430 ppm and 935 ppm respectively), which are both naturally ventilated through openable windows, suggesting an issue with the mechanical ventilation system in room 1.

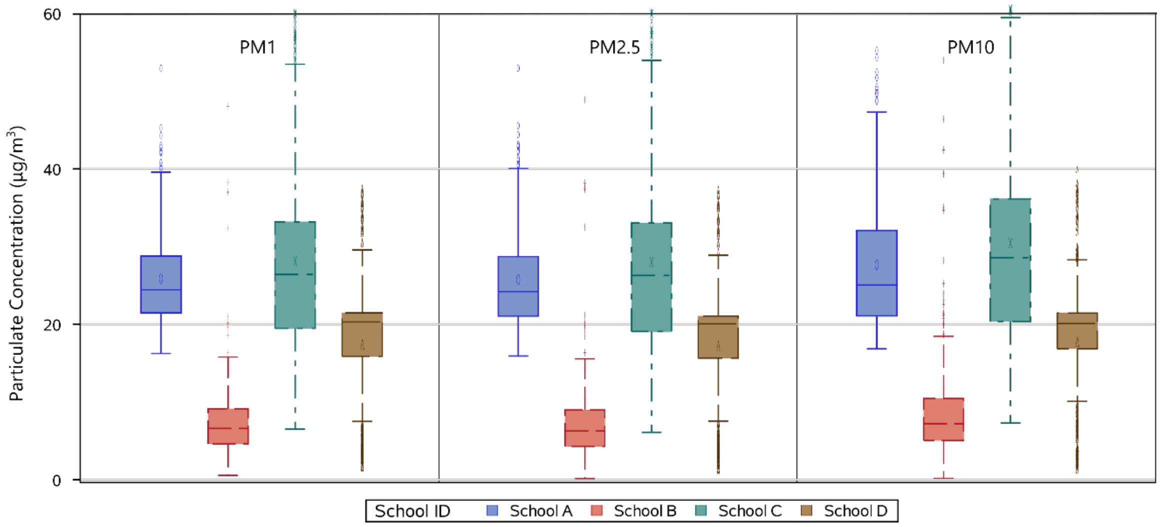



**Figure 11.3 – Internal concentrations of PM1, PM2.5 and PM10 at each school during occupied hours**

Due to logger issues, no external values for the particulates were recorded, but the internal concentrations shown in Figure 11.3 show clear differences between the four schools. School A and School C are regularly above the WHO $PM_{10}$ daily exposure limit[23] of 20 µg/m$^3$ (School A $PM_{10}$ mean: 27.6 µg/m$^3$, School C $PM_{10}$ mean: 30.5 µg/m$^3$). School D has a mean value just below the daily exposure limit of 17.6 µg/m$^3$, and school B is much lower at 11.7 µg/m$^3$ for $PM_{10}$. Although the exact cause of the high PMs at School C is unknown, it is the oldest of the four

[23] Note that the WHO limits on $PM_{10}$ are broadly applicable to $PM_{2.5}$ and $PM_1$, but there are no exposure values given.

schools, with widespread original carpeting throughout the circulation and classrooms, potentially harbouring a build-up of particulates that could account for the higher levels.

As with the PM concentrations, the TVOC concentrations measured at each school vary widely (see Figure 11.4), with School B (mean: 0.036 ppm) much lower than the other three and lower than the typical values found by Chatzidiakou et al. ( Chatzidiakou et al., 2012) of 0.04-0.06 ppm[24]. School A was within these typical values (mean: 0.058 ppm), whereas School D was over double (mean: 0.133 ppm) and School C was over three times the typical concentrations (mean: 0.183 ppm). Within school C, the science room tested had very high mean concentrations (0.395 ppm) and reaching 1.070 ppm, caused by experiments during the lessons using organic solvents. The other two rooms had lower concentrations, with one within the typical range noted by Chatzidiakou et al. and one higher (room 1: 0.057 ppm, and room 3: 0.097 ppm). Also notable is that the mean external concentrations at schools A, B and D are higher than internal concentrations, particularly at School B which has an external concentration nearly three times the typical internal conditions (mean: 0.177 ppm).

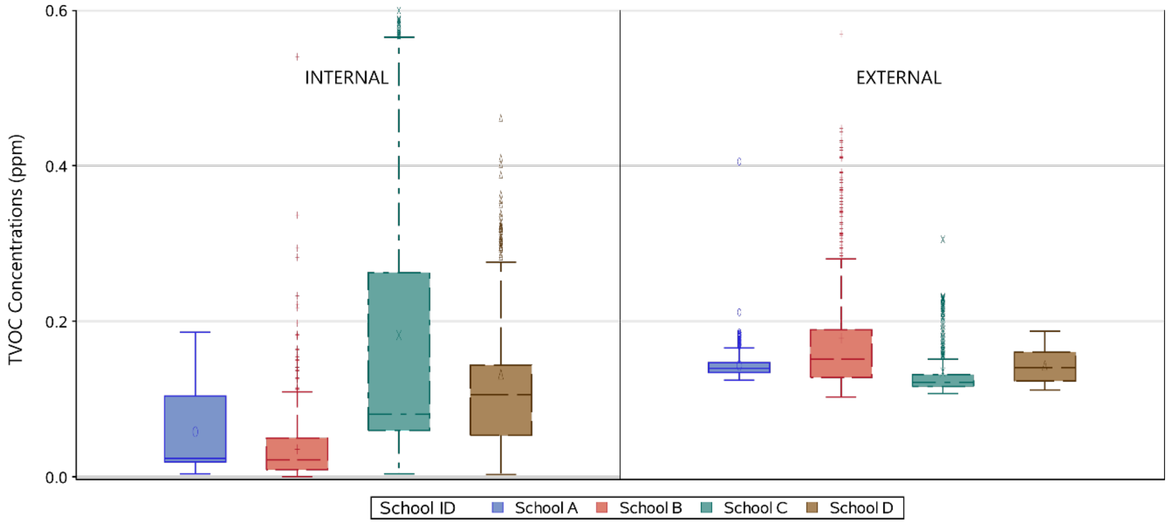



**Figure 11.4 – TVOC measured concentrations at each school during occupied hours.**

All four schools were below the WHO daily exposure limit for $NO_2$ of 40 µg/m$^3$, despite the external concentrations at School B breaching the limits, see Table 11.1. Not surprisingly, the $NO_2$ concentrations of the urban setting at School B are highest (means 27.2 µg/m$^3$), with School A

[24] Chatzidiakou et al (2012) gave values in µg/m$^3$, however converting TVOCs into µg/m$^3$ requires the molecular weight, which is impossible without further testing as the TVOCs by definition is a collection of different compounds. For comparison purposes, the molecular weight of isobutylene has been used (56.11 g/mol) as it is used to calibrate the TVOC logger.

recording the lowest concentrations (mean: 5.1 μg/m$^3$) reflecting the variation between urban and semi-rural air quality. The level Pilotto (1997) found gave rise to increased absenteeism, 150 μg/m$^3$, is much higher than those found at these four schools.

**Table 11.1 – Mean concentrations of passively sampled internal and external $NO_2$ for each school**

| | School A | School B | School C | School D |
|---|---|---|---|---|
| NO2 Internal Concentration (μg/m$^3$) | 5.1 | 27.2 | 9.7 | 5.8 |
| NO2 External Concentration (μg/m$^3$) | 8.6 | 40.4 | 13.0 | 11.1 |
| Difference in NO2 between inside and outside (μg/m$^3$) | -3.5 | -13.3 | -3.3 | -5.4 |

### 11.1.2 Acoustic performance

Within all four schools, the mean reverberation times were above the recommended value of 0.6 seconds by Building Bulletin 93 (DfES, 2003) and Crandell and Smaldino (2000) as shown in Table 11.2, with only room 3 within School D meeting the recommended level at 0.59 seconds. No clear pattern was observable between the typical classrooms and the science rooms, with the longest reverberation time with room 3 at School B of 0.78 seconds. Within School A, there is little difference in reverberation times between open-plan room 1 (T60: 0.66 seconds) and the more typical room 3 (T60: 0.65 seconds).

Mean average noise levels at School A and School B were below the recommended 35 dBA from Building Bulletin 93, despite the high ambient noise level at School B (see Table 11.2). Schools C and D were both above the 35 dBA threshold. At School C this was caused by one particularly noisy classroom (room 2) with an $L_{Aeq, 5}$ dB of 40.4 dBA and the other two classrooms passing the recommend value (room 1: 32.7 dBA, and room 2: 29.6 dBA). Room 2 at School C is far more exposed to road traffic noise than the other two rooms, as the closest to the road and on the first floor with no shielding from the landscaping. Within School D, room 1 was much quieter (29.1 dBA) than the other two rooms (Room 2: 37.4 dBA and Room 3: 38.9 dBA), despite being on the noisier side of the building, overlooking a busy road. However, room 1 has a sealed façade to prevent noise from the nearby road, relying on mechanical ventilation for fresh air, and the other two rooms use openable windows, suggesting that they are not as acoustically robust.

**Table 11.2 – School mean averages for noise (note ambient noise levels are without ventilation systems operating)**

| | School A | School B | School C | School D |
|---|---|---|---|---|
| Reverberation time (T60, secs) | 0.65 | 0.70 | 0.64 | 0.66 |
| Internal Ambient Noise Level ($L_{Aeq,5}$ dB) | 30.1 | 30.2 | 36.7 | 36.7 |
| External Ambient Noise Level ($L_{Aeq,5}$ dB) | 46.4 | 64.1 | 56.5 | 58.9 |

### 11.1.3 Daylight levels

The daylight levels given in Table 11.3 show that on average the teaching spaces could not be considered fully daylit by Building Bulletin 90 (Department for Education., 1999), with School D achieving the highest daylight factor at 4.6 %, assisted by the only space measured that achieved over 5%; room 1 at 6.9%. All schools will be able to be partially daylit, but requiring additional lighting at times throughout the year. However, room 1 at school C achieved a very low factor of 0.4%, suggesting that it will require artificial lighting throughout the year to function. This room on the ground floor had windows partially covered with posters and large plants outside that covered the glazing preventing daylight reaching the space. It should be noted that despite how much daylight the rooms could receive, each room tested in all four schools had to have the blinds opened up to allow the daylight in. Discussions with teachers suggested that the overriding reason for the closed blinds was the difficulty of seeing the interactive white boards with the additional daylight.

**Table 11.3 – School mean averages for daylight factors**

| | School A | School B | School C | School D |
|---|---|---|---|---|
| Daylight Factor | 2.7 % | 4.2 % | 1.8 % | 4.6 % |

### 11.1.4 Measured internal environment summary

Across the eight measured aspects of the built environment, no school reached full compliance across every aspect, as shown in Table 11.4. School B had the greatest rate of compliance, only failing on reverberation times, with School A also failing to meet reverberation times, but also recording high levels of particulates. School D in addition to issues with reverberation and particulates, also failed to meet internal ambient noise levels. School C had the poorest performance against the compliance criteria, failing to meet 5 of the 7 defined criteria, with low daylight factors and high $CO_2$ levels measured within the rooms.

**Table 11.4 – Summary table showing the environmental compliance for each of the schools across each of the eight measured environmental aspects (note no defined limits for TVOC concentration has been set)**

| Internal Environment Aspect | Limit | Limit Exceeded | | | |
|---|---|---|---|---|---|
| | | School A | School B | School C | School D |
| Temperature | 28°C | No | No | No | No |
| $CO_2$ | 1,000 ppm | No | No | *Yes* | No |
| Particulates | 20 μg/m$^3$ | *Yes* | No | *Yes* | *Yes* |
| TVOC | No defined limit | - | - | - | - |
| $NO_2$ | 40 μg/m$^3$ | No | No | No | No |
| Reverberation Times | 0.6 seconds | *Yes* | *Yes* | *Yes* | *Yes* |
| Internal Ambient Noise Level | 35 dBA | No | No | *Yes* | *Yes* |
| Daylight Factor | 2% Minimum | No | No | *Yes* | No |

## 11.2 School Climate Questionnaire

Out of the four schools selected for the case study, three completed the full school questionnaire, with School D opting out of the school climate section. However, School D was unable to provide a statistical significant sample, with the power, $\beta$, of only 0.264 (r = 0.2, α=0.05, one-sided), far short of the 0.8 recommended by (Cohen, (1992) via Field and Miles (2010)) (see Table 11.5). As such the completed questionnaires from school D have been removed from the analysis to prevent misrepresenting the school environment. The number of responses from school B also creates a sampling power, $\beta$, below the 0.8 threshold, but when the correlation size is increased to 0.25, the power increases to 0.880. Additionally, the schools will be treated together, giving a much larger power than reported for each school.

**Table 11.5 – The number of student questionnaires returned by each school and sampling power, $\beta$, for correlation coefficient r= 0.2, using Fisher's z transformation and assuming normal approximation**

| School ID | Number of responses, $N$ | Total Number of Students | % coverage of Students | Power, $\beta$, at r = 0.2 |
|---|---|---|---|---|
| **A** | 173 | 724 | 24% | 0.843 |
| **B** | 124 | 840 | 15% | 0.724 |
| **C** | 233 | 1376 | 17% | 0.925 |
| **D** | 27 | 618 | 4% | 0.264 |

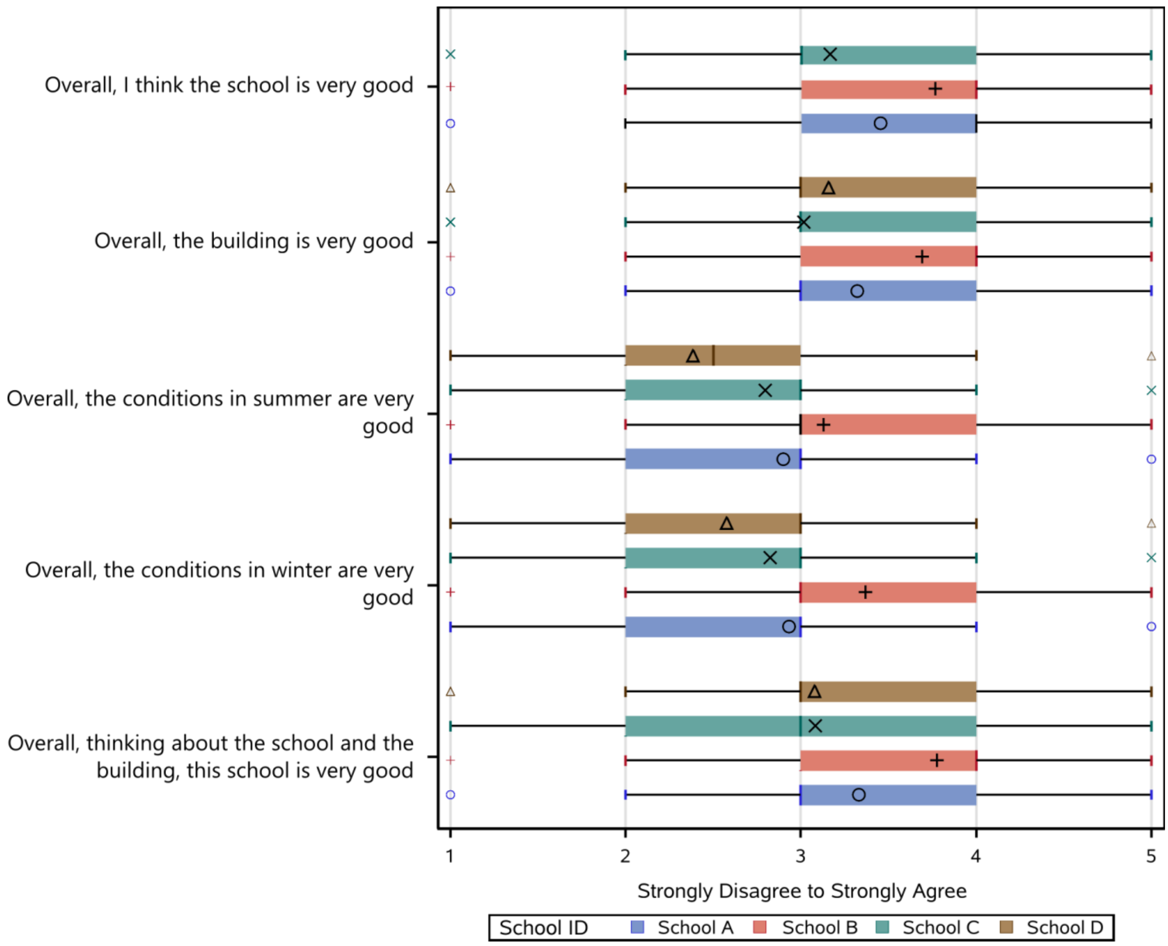



**Figure 11.5 – Box plot showing the results of the summary questions from the student questionnaire by school (note School D did not complete the section containing the top question)**

Exploring the responses from the students shows that overall the students were satisfied with the building, despite three of the four schools being rated negatively for internal conditions in both summer and winter (see Figure 11.5 for summary box plot and Appendix D for the full set of box plots). School B was the only school to report better than neutral satisfaction with the internal conditions during summer and winter, which is expected given the good air quality measured and reflects the high satisfaction with the building overall. This is also likely linked to the highest overall satisfaction for the school found at school B. The satisfaction with the building despite the perception of a poor environment suggests that it is not as important as other aspects of the building that were rated highly, such as the aesthetics. The interval for the responses for each school in the overall responses was small, with only school C having a slightly larger distribution for the final overall question.

Looking at the perceived air quality in schools A, B, and C, shown in Figure 11.6, it can be seen that school B is perceived as having a better IAQ than the school A and C. School B is the only school to have a positive mean in any of the four IAQ categories, winter air smells, however all other means are below neutral. Schools A and C have similar results, with summer air smells rated poorly at both schools. As noted above, school B has good air quality, with low TVOC, PM and $CO_2$ concentrations recorded during the end of the winter period. Despite school C having the highest concentrations of TVOCs, $CO_2$ and PMs of the four schools, the air quality is rated similarly to the air quality in school A, with only the summer air being clearly perceived as more 'smelly'. Without measuring the summer air quality, it is difficult to quantify the underlying reason for this difference. The lack of variation despite the measured difference indicates that the students may not notice the poor IAQ or struggle to quantify the levels beyond simple good/bad ratings. Alternatively, the spaces measured might be outliers within the buildings.

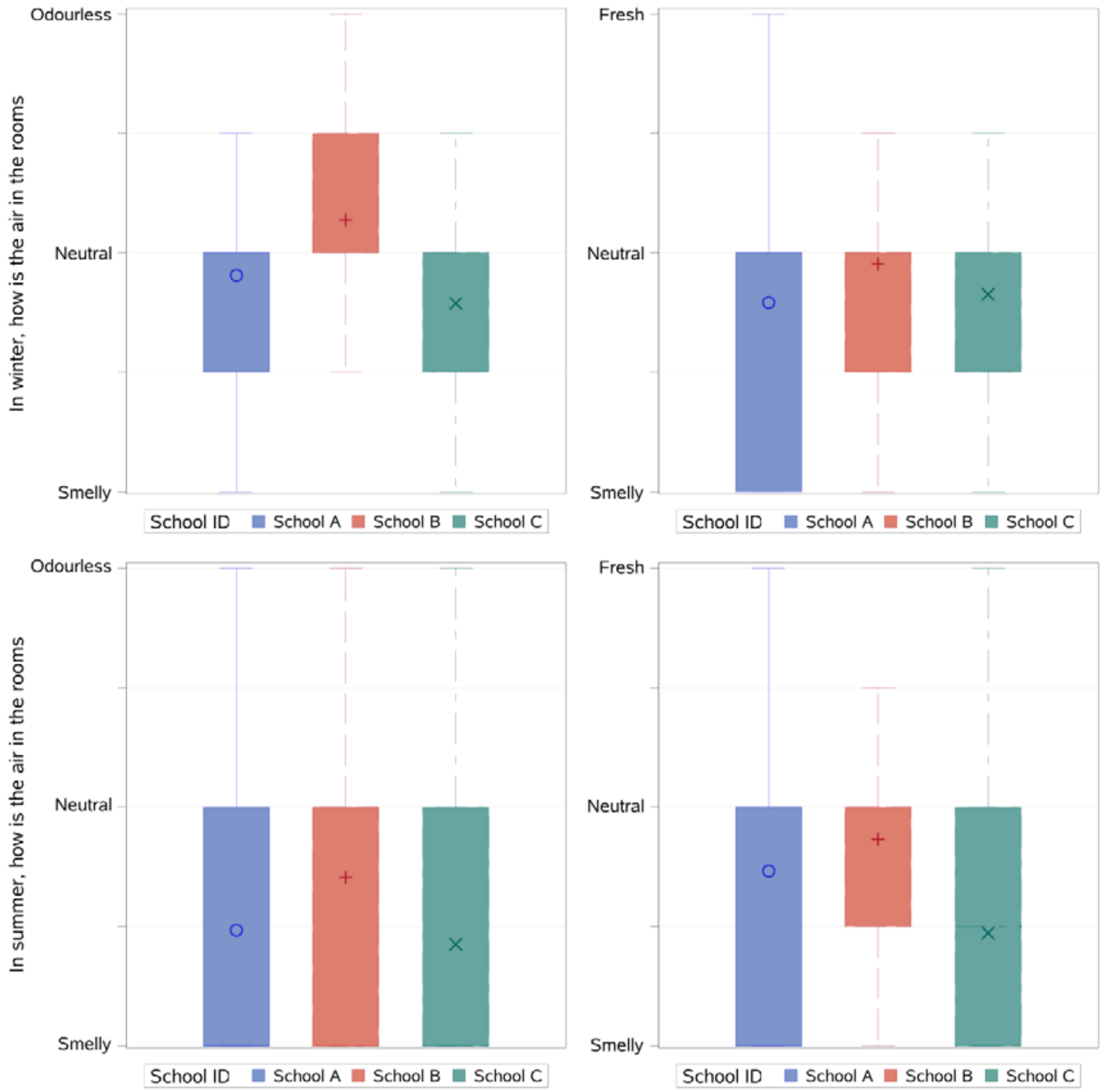



**Figure 11.6 – Box plots showing perceived air quality in schools A, B and C**

Responses to the temperature questions for the schools, shown in Figure 11.7, highlights that the students perceive the school as being too cold in winter and too hot in summer, although School B is closer to ‘perfect’ than schools A and C. The measured temperatures for all three schools at the end of the heating season found the temperatures were within a region defined as comfortable by Wargocki and Wyon (2007), indicating that the questionnaire results may not be true reflections on the actual temperature experienced during these seasons.

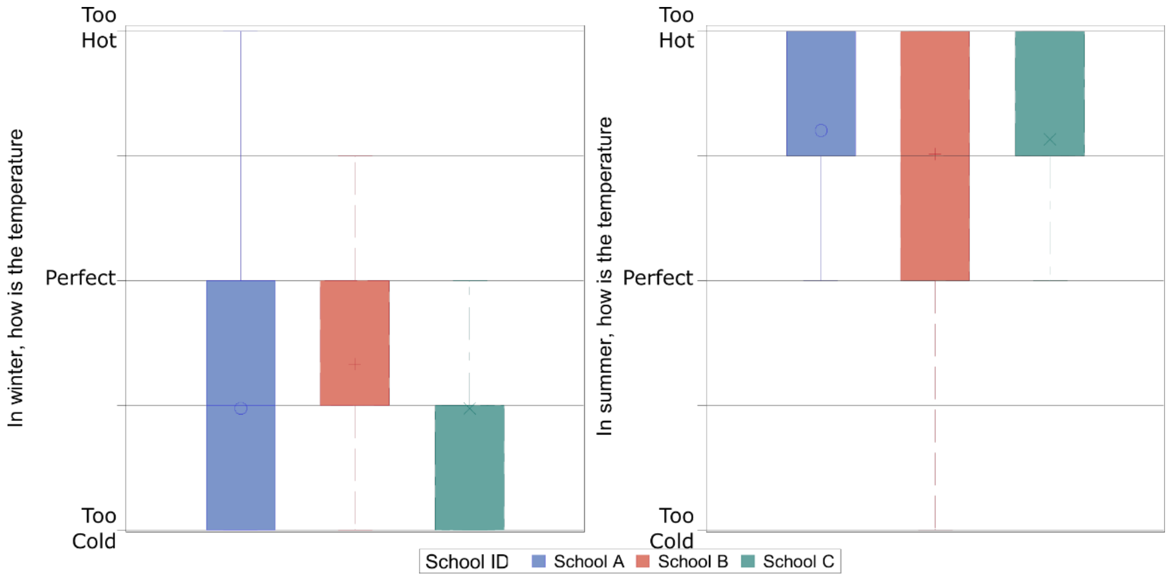



**Figure 11.7 – Boxplots showing the questionnaire satisfaction on the internal temperature for winter (left) and summer (right)**

### 11.2.1 Principal Component Analysis

The principal component analysis was carried out on the normalised questionnaire responses, with school D omitted due to the low response rate and lack of school climate section. As with all factor analyses, all blank responses were omitted, leaving 362 questionnaires out of the full 530 received from school A, B and C. Excluding the background section, 45 questions were examined, covering the school climate, building aesthetics, comfort, acoustics, daylighting and overall perceptions of the school and building.

Analysing the correlations between the different questions using Kaiser's Measure of Sampling Adequacy (MSA) found an overall value of 0.941. The Kaiser's MSA is a measure of inter-correlation between variables that may skew results when performing a factor analysis. Hutcheson & Sofrouniou (1999) state that an MSA over 0.9 should be considered very good, and likely to produce robust results. Once the suitability of analysis had been established, the eigenvalues were calculated, with 45 eigenvalues produced (the same number as the number of questions assessed), all of which are shown in the scree plot in Figure 11.8. Taking 1.0 as the cut-off for factors to be taken forward kept 10 factors, but it can be seen from Figure 11.8 that the factors from 5 onwards are of a similar magnitude, with differences between them at this point is minimal. As such, a point of inflexion was chosen at factor 5, which is the final factor before the scree plot flattens out.

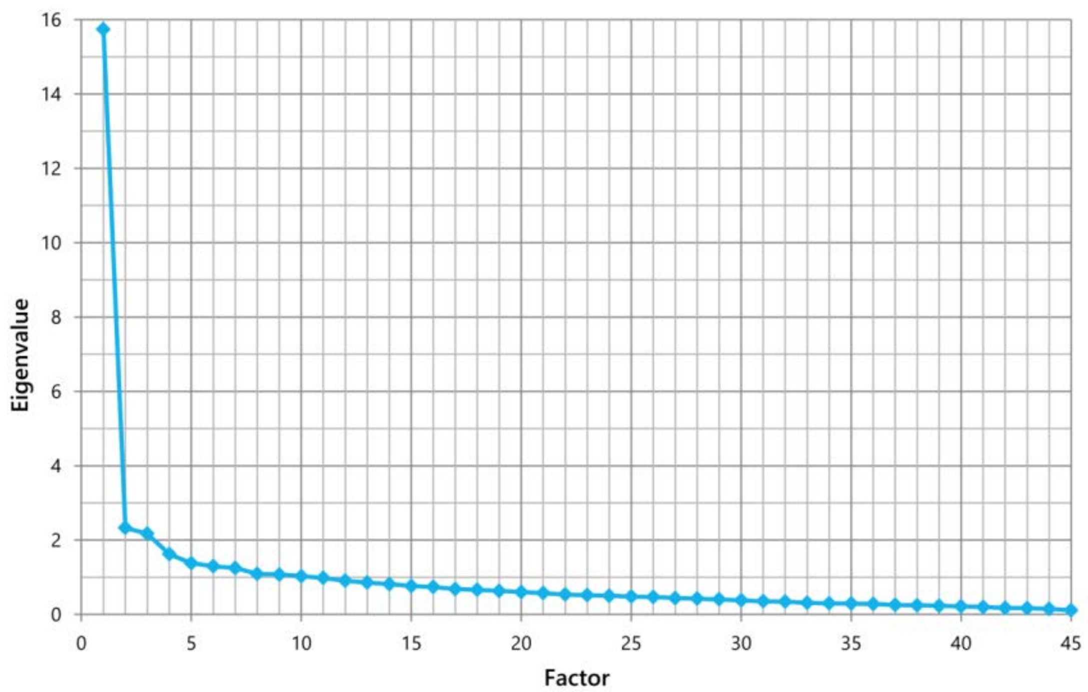



**Figure 11.8 – Scree plot showing eigenvalues generated from principal component analysis of student questionnaire**

The questions were then split into the five factors according to their specific correlation coefficient within each factor (note that they are able to be in more than one factor). Interpolating from Stevens' given critical values (Stevens, 2012, p. 332 table 11.1) gives an absolute critical value of 0.270, with questions achieving this value (either positively or negatively) assigned to that factor (see Appendix E for the full list of questions assigned to each factor). Evaluating these questions within the factors allows them to be interpreted as follows, with the percentage of variance explained by each factor in brackets:

- *Factor 1*: The appearance and 'feel' of the school (38.6%)
- *Factor 2*: The school climate and winter temperature (29.8%)
- *Factor 3*: Student interactions (14.7%)
- *Factor 4*: Summer comfort, way-finding and extra time within the school (10.0%)
- *Factor 5*: Daylighting (6.9%)

Factor 5 solely focuses on the daylight questions, potentially due to their different scoring, but also indicating that the perceived daylight has little influence over the overall perceptions of the school. Factor 4 provides a mix of themes with little coherence or clear underlying pattern. However, examining the responses (in Appendix D), it is clear that these are the questions that had the greatest consensus amongst the responses, with either strong negative or positive means for each school. It is likely this factor represents aspects of the building that have common perceptions within each school.

The school climate is strongly represented by factor 2, including nearly all the school climate questions outlined by Zullig et al (2010) (excepting the negatively worded Q14, see Appendix E), but also including way-finding and the winter temperature. The omitted question was the only school climate question worded negatively regarding fairness of lessons, which may have caused its omission from this factor. It is useful to see the general separation of the school climate and the built environment is possible within the students, suggesting that they are capable of largely unbiased opinions on either. However, it is unclear why the winter temperature and the wayfinding would relate to the school climate, with no clear pattern evident in the responses. It may be that the tolerance of these aspects of the building are an indicator of the school climate, with an improved climate indicating greater tolerance. Closely related is factor 3, which covers the social interactions of the students, but reflecting the negative side of these interactions as opposed to the largely positive questions of factor 2. The strongest factor, factor 1, is centred on the look and feel of the school, with the overall school climate and rewards also included.

Through these factors there is clear delineation of the different aspects of the school climate, with factor 1 joining the look and feel of the school with rewarding students, factor 2 collating the academic support, order/discipline, and school connectedness, and factor 3 capturing the school social environment and exclusion. Within the work of Zullig et al (2010), they found seven factors that covered the school climate, covering the areas found in factors 1, 2, and 3. The additional environmental factors are less well delineated, with only the daylighting clearly separate but explaining lowest amount of variance.

## 11.3 Summary

The environmental performance in the four case study schools has been measured along with the students' perception of their school environment. The environmental measurements found that all four schools have comfortable environments, rarely exceeding the guideline levels, and the questionnaire analysis showed the links between the measured environment and the perceived environment is weak. However, the questionnaire did show the underlying factors determining the students' perception of their environment.

*Good internal environmental quality was measured at each school*

The environment at each school passed the design guidelines set out by the relevant building bulletins and the World Health Organisation (WHO) limits, with two notable exceptions: high PM concentrations at Schools A and C (School A mean $PM_{10}$ 27.6 μg/m$^3$, School C mean $PM_{10}$ 30.5 μg/m$^3$ compared to a WHO limit of 20 μg/m$^3$) and high TVOC concentrations at Schools C and D (School C mean: 0.133 ppm, School D mean: 0.183 ppm). Although relatively high $CO_2$ levels were found at School C, these were still lower than those found by Mumovic et al.'s (2009) study into schools, with schools A, B and D having very low concentrations. $NO_2$ at each school was below the WHO limits (40 μg/m$^3$), despite the external air quality at School B reaching 40.4 μg/m$^3$. Without measuring the building in the warmest or coldest weather, it is difficult to ascertain the limits of the schools performance. In addition, the perceived environment undoubtedly contains memories of these extreme events and the ability of the students to create an accurate average is not guaranteed.

*Daylight is an issue at all four schools*

School C had a notably low mean daylight factor of 1.8%, below the threshold for any daylight autonomy of 2% as defined by Building Bulletin 90, and only one room measured over the 5% threshold required to achieve predominant daylight autonomy (room 1 at school D: 6.9%). However, within all of the measured spaces the blinds were closed to such an extent that daylight readings were not possible, blocking any of the benefits associated with the glazing, whether it is the daylight (for example Heschong et al (2002)) or the connection to the outside (as discussed by Yildirim et al (2007)).

*The look and feel of the school was the most important factor in the student perceptions*

Perceptions of the school environment were found to have five underlying factors, with the look and 'feel' of the school the top influencer, accounting for 38.6% of difference between opinions. This was above the school climate, which accounted for 29.8% of the variance, and student interactions which represented 14.7%. The fourth factor, covering a mix of aspects with uniform string feeling at each school including summer comfort, wayfinding and additional time within the school, represented 10.0% of the variance. The fifth factor, daylighting, represented 6.9% of the overall variance. Finding that the school climate is less important than the look and feel of the school contradicts the work of Zullig et al (2010), who found that the student-teacher relationship was by far the most important aspect (accounting for 27.6% of variance), and the school physical environment much less important (accounting for 2.4% of variance). It is likely that there is an interplay between the look and feel of the school and the school climate in a subtler way, reflecting the overlap discussed by Tagiuri et al (1968). The questionnaire analysis has been hampered by the inclusion of only three of the four schools due to low return rates. School D did not want the students to complete the school climate questionnaire section and was reluctant to encourage the questionnaire among staff.

# 12 Methodology – Co-Analysis of School Level Data

At the school level, four different techniques have been applied; ISAT, questionnaires, space syntax, and environmental measurements. These have so far been treated in isolation, however a key novel step in this research is bringing these together to gain a greater insight into the student perception of their space. Within this chapter and the following results chapter, the methods for analysis will be discussed, starting with the analysis of movement within the ISAT using the space syntax results, then the multi-level modelling of the ISAT, questionnaire, and environmental data will be introduced.

## 12.1 ISAT Navigation Analysis

Given that the ISAT creates a virtual version of each school, it provides the opportunity to provide insight in to how the students move through the building. As the ISAT creates an approximation of the building as a series of points with a panoramic view (see Figure 6.2), the movement can be compared to the Visual Graph Analysis (VGA) results obtained in section 8. From the VGA point based metrics were produced; integration (HH), and mean depth (MD). Both of these space syntax metrics have been shown to correlate with observed movement (Sailer, 2010), and the level of correlation between the movement within the ISAT and the VGA results would be indicative of the type of movement through the school building.

To enable comparisons between the movement within the ISAT and the VGA, the values of both integration (HH) and the VMD were taken at the point the ISAT space image was taken. The VGA analysis approximates an isovist from that chosen point (Turner and Penn 1999) which can be seen as analogous to the panoramic images of the ISAT and therefore is the closest representation of the ISAT environment. Using the point values of the VGA for each school, these were then compared to the average number of visits per user that the corresponding space received using regression analysis, producing an $R^2$ value as an indicator of the type of movement. Given that the classrooms represent end destinations and the circulation spaces represent links between these destinations, the circulation and non-circulation spaces were analysed separately to determine whether the overall $R^2$ value is dictated by a type of space.

## 12.2 Multi-Level Modelling Introduction

To understand the student perceptions of their environment, a key aspect of this work is the multilevel modelling of the data, enabling the qualitative and quantitative data to be co-analysed in a robust manner. Within the results of the school-level case study, there are currently three sets of data:

- Questionnaire results as discrete values from Likert-type scale (at school level and student level)
- Environmental data as continuous scale (at school level and room level)
- ISAT results as a continuous scale (at school level only)

Perhaps one of the quickest methods of comparing the data is through simple regression analysis, providing easily intelligible coefficients relating two or more data sets. However, within simple regression the hierarchy of the data is lost, for example the influence of the school on the students, leading to loss of data fidelity. For this reason, the school data will be analysed using multi-level modelling, where the hierarchical structure can be kept as an integral part of the analysis. This has been widely used for modelling school level data (as used within MlwiN's manual (Rasbash, Steele, Browne, & Goldstein, 2014)), and for medical data (Goldstein, Browne, & Rasbash, 2002), enabling the data structure to be preserved during analysis.

The modelling will take the form of three separate analyses, each using similar methods, but accounting for the differing data types:

1. Questionnaire results and environmental measurements
2. ISAT results and questionnaire results
3. ISAT results and environmental measurements

Comparing the questionnaire and environmental analysis will require the construction of a model that accounts for the different levels of the data. While many statistical packages are able to effectively deal with multilevel modelling, (see Zhou et al. (Zhou, Perkins, & Hui, 1999), or Leeuw and Kreft (2011) for discussions on multilevel modelling programs), each with advantages and disadvantages to their specific approach. Given the complex nature of the data, it was decided to use University of Bristol's MlwiN, developed by their Centre for Multilevel Modelling (Rasbash, Charlton, et al., 2014), which is specifically designed for multilevel modelling and developed to support research. While other software packages are able to undertake multilevel modelling (for example Singer's discussion on using SAS (Singer, 1998)), no other package was found to be able to accommodate the discrete data efficiently.

## 12.3 Modelling Questionnaire Results and Environmental Data

The multilevel model was used to find the relationships between the measured environment and the questionnaire results. Comparing the questionnaire and environmental data requires mixing the discrete, multinomial questionnaire results with the continuous, longitudinal environmental data. Additionally, within the environmental data, there is a mix of longitudinal data from the loggers (temperature, humidity, $CO_2$, TVOCs, and PMs) with averaged data from the $NO_2$ absorption passive samplers and one-off measurements (daylight, ambient noise levels, and reverberation times). As the questionnaire data is not concurrent with the environmental data (the questionnaires were completed separately) there is no benefit from examining the data longitudinally, instead mean averages were used. As the questionnaire captures the experiences of the students within the school, the longitudinal data was averaged during the operating hours, taken as the period defined within Building Bulletin 101 (DfES, 2006); 9am to 3:30pm[25]. For each of the spaces monitored the mean average during this period was calculated for the temperature, humidity, $CO_2$, TVOCs, and PMs.

As the questionnaire data is not aggregated to the spaces monitored, there was no benefit from the preserving this structure within the analysis, instead the data was merged to form indicative building environmental performance. This took the form of a mean of the occupied time averages for all data recorded, except the ambient noise levels. As the ambient noise levels are based on the A-weighted log scale, the noise levels were first converted from decibel to sound power, mean averaged, then converted back to decibel, ensuring a valid mean is found.

To robustly compare the questionnaire data with the environmental data, a 2-level multinomial logistic model will be constructed for each question, allowing the mix of continuous and discrete data. There are three general types of logistic link functions available within MlwiN: logit, probit, and complimentary log-log (Clog). Collett (Collett, 2003, sec. 3.5) explores the differences

[25] Note the schools did operate outside of these hours, but not within the monitored rooms.

between these functions, noting that Clog is used only for particular distributions (Gumbel distribution), which is not in effect within these data. The probit and the logit functions can be used almost interchangeably, however Collett and Rasbash et al (Collett, 2003; Rasbash, Steele, et al., 2014) note that the interpretation of logit models is significantly easier, hence the logit link function will be used over the other two functions.

Within the multinomial modelling, each response variable (a number from 1-5 in the case of the used questionnaires) is compared to a baseline response that can be set. MlwiN allows the response variable can be set as ordinal, with each subsequent response variable compared the previous, however this caused instability within the software so could not be used. As such, each response variable was compared to the base response, set as the ‘1’, representing the most negative response for a majority of the questions. This ensures that the results can be interpreted in a more natural way, with positive results representing increasing positivity.

$$
\begin{aligned}
y_{ijk} &\sim \text{Multinomial}(n_{jk}, \pi_{ijk}) \\
\log(\pi_{2jk} / \pi_{1jk}) &= \beta_0 x_{0ijk} + h_{jk} \\
\log(\pi_{3jk} / \pi_{1jk}) &= \beta_1 x_{1ijk} + h_{jk} \\
\log(\pi_{4jk} / \pi_{1jk}) &= \beta_2 x_{2ijk} + h_{jk} \\
\log(\pi_{5jk} / \pi_{1jk}) &= \beta_3 x_{3ijk} + h_{jk} \\
h_{jk} &= \beta_{4k} x_{4k} \\
\beta_{4k} &= \beta_4 + v_{4k}
\end{aligned}
$$

$$
\left[ v_{4k} \right] \sim \mathrm{N}(0,\ \Omega_v) \ : \ \Omega_v = \left[ \sigma^2_{v4} \right]
$$

**Equation 12.1 – 2nd Order multinomial equation used for comparison of questionnaire and environmental data with $\pi_{1jk}$ representing the base condition**

*$y$ = dependent variable (question)*
*$n_{jk}$= constant (in this case 1)*
*$I$ = response level*
*$j$= student level*
*$k$=school level*
*$\pi_{ijk}$= probability of $y_{ijk}$= 1*
*$x_{0 \text{ to } 3ijk}$ = composite response indicator*
*$\beta$ = variable coefficient*
*$h$= common coefficient*
*$x_{4k}$= independent variable (environmental factor)*
*$v_{4k}$= variance between school level variable*

MlwiN operates as an iterative calculation engine, approximating the model with successive approximations until the difference in results do not alter. As recommended by Rasbash et al (2014) with 2nd order multilevel models (see Equation 12.1), the most efficient manner to calculate the coefficients is to start with 1st order Marginal Quasi-Likelihood (MQL) estimation, followed by 2nd order Penalised Quasi-Likelihood (PQL) estimation, using the final estimation of the MQL analysis as the starting point for the PQL. The greater accuracy of the 2nd order PQL method can be hampered by the initial estimation and fail to converge if the starting estimate is too misleading.For each question within the questionnaire that has a corresponding measured environmental factor, the link between the environment and occupant perception can be investigated using Equation 12.1. The coefficient ($\beta_{4k}$) indicates the strength of the relationship between the independent and dependent variables, with variance between the schools given by $v_{4k}$. Coefficients $\beta_0$ to $\beta_3$ represent the likelihood of each level each categorical response compared to the base response. Significance of the coefficients can be found using the standard error and normal distribution (Collett, 2003), with the significance level set to $p<0.05$. By calculating the logit equation with the specific and environmental coefficients, the likelihood ratio of each categorical response occurring compared to the base response can be found.

## 12.4 Modelling ISAT Results and Environmental Data

As with the questionnaire data, it is important to understand the links between the reported environment and the measured environment. With a new tool such as the ISAT, it is important to understand how the responses relate to the physical environment, hence the need to compare the ISAT results to the measured environmental properties. Using multilevel modelling enables the links between the ISAT results and the measured environment to be quantified using robust statistical analysis, bringing together the qualitative and quantitative elements in a rigorous manner. As discussed within section 12.5, the ISAT data needs to be analysed using the positive and negative polarity responses separately, rather than using the total occurrences. This ensures that attitudes towards the environment can be accurately modelled.

The ISAT data itself is percentage of overall occurrences for each property, for each school. While this data does have two levels, student and school, the student level contains very little information, with many gaps where the student has not noted specific aspects. Instead the data is aggregated by property into school level data as a percentage of overall property occurrence for each school. A consequence of this aggregation is that the data now requires a 1st order model. As with the questionnaire, the ISAT results can be thought of as the response, or dependent variable, and the environmental variable as the independent variable.

In order to represent the ISAT data accurately, the model must be constrained to between 0 and 1, acknowledging the fact that it is a percentage. MlwiN provides three methods of representing such data: binary, binomial (or Bernoulli), and Poisson distributions (Rasbash, Steele, et al., 2014). The binary distribution is much like the multinomial constrained to one outcome, 0 or 1, and consequently does not accept fractional values. The Poisson distribution is able to accommodate percentages while constraining the values between 0 and 1. However the Poisson distribution needs an expected likelihood of occurrence, something which is very difficult to estimate for an unused tool. With the binomial distribution, it is extension of the binary model that accepts fractions, using the event count data to control (Collett 2003). In the case of the ISAT this count data is the overall number of property occurrences at each school. Using this binomial model, the ISAT data can be effectively compared to the environmental data.

$$y_i \sim \text{Binomial}(n_i, \pi_i)$$
$$\text{logit}(\pi_i) = \beta_0 x_0 + \beta_1 x_{1i}$$

$$\text{var}(y_i|\pi_i) = \pi_i(1 - \pi_i)/n_i$$

**Equation 12.2 – 1st Order general binomial model for comparison of the ISAT results and environmental data**

*$y$ = dependent variable (question)*
*$n_i$ = count data*
*$I$ = school level*
*$\pi_i$ = probability of $y_i = 1$*
*$x_0$ = constant of 1*
*$x_1$ = independent variable (ISAT property)*
*$\beta$ = variable coefficient*
*$h$ = common coefficient*

Similar to the multinomial modelling used earlier, the logit link function has been used for its simplicity in analysis (as seen in Equation 12.2). The two coefficients in Equation 12.1, $\beta_0$ and $\beta_1$, relate to the variance between the school and the influence of the independent variable respectively. By comparing the coefficient $\beta_1$ of different environmental aspects, the relative influence of these aspects on the ISAT responses can be identified.

## 12.5 Modelling ISAT Results and Questionnaire Data

Although the ISAT properties generated by the grounded theory analysis are significant due to their unguided nature, to understand the characteristics of this type of survey method it was compared to the questionnaire. The questionnaire is a well understood tool, so by comparing the two it will inform future analysis of the ISAT. Similar to modelling the questionnaire and environmental results, modelling the questionnaire and ISAT results requires a 2nd order multinomial model, with one level for the students and one for the school, and the questionnaire results as the dependent variable and ISAT responses as the independent variable (see Equation 12.1). This multilevel model produces a correlation coefficient that separates out the effect of the school, indicating the variance that can be explained by the correlation coefficient for the independent variable.

Within the ISAT results, there are two subsets of data, positive and negative responses, which are percentages of the overall property occurrences for that school. These positive and negative responses were used in the model rather than the total property occurrence. By using these polarity subsets rather than the total occurrences, the sentiment of the ISAT responses can be better understood. Only those sections that are linked will be modelled. Given the highly exploratory nature of both the ISAT and the holistic methodology, a significance of 0.05 has been set, enabling links to be exposed for future analysis at higher significance levels.

# 13 Results – Co-Analysis of School-Level Data

Within chapters 7, 9, and 11, the results of the different tools applied to the school level case studies have been presented, largely in isolation from each other. Within this chapter the results of the ISAT navigation and the multi-level modelling are presented, bringing together the different methods used with a robust statistical procedure to identify any underlying connections between the measured and perceived environment. First the ISAT navigation will be presented, followed by the three multi-level models. The first two multi-level models compare the environment with the perceived environment (from the questionnaires and the ISAT), and the third section comparing the two perception feedback tools.

## 13.1 Space Navigation

Visually comparing the Visual Graph Analysis (VGA) results of each school with the movement through the ISAT, shown in Appendix F, the patterns of movement recorded by the ISAT resemble the pattern observed in the visual integration[26] at each school. A regression analysis of the point integration and the average number of visits per user, shown in Figure 13.1, shows that Schools A, C and D have stronger correlation coefficients ($R^2$=0.598, $R^2$=0.566 and $R^2$= 0.554 respectively) than School B ($R^2$=0.353)[27]. Figure 13.2 indicates a similar pattern of separation between schools A, C and D and school B can be observed when using mean depth[28] instead of integration values (School A $R^2$ = 0.523, School B $R^2$ = 0.249, School C $R^2$ = 0.495, School D $R^2$ = 0.426), although all correlation values are lower than those found using integration as a metric.

[26] The integration represents the ease of visual connection through the school, with higher values suggesting a building that is more connected.
[27] Note that the VGA values used are taken from the same point as the camera location in each space as this is the same isovist as visible within the ISAT. For a comparison, the average integration value for each space within the ISAT was used, finding close correlation coefficients (School A, $R^2$ = 0.573; School B, $R^2$ = 0.323; School C, $R^2$ = 0.625; School D, $R^2$ = 0.515;), with an average difference across the four schools of 7.4%.
[28] The mean step depth shows the mean number of visual turns required to see every other point of the building, with lower values suggesting great visibility within the building layout.

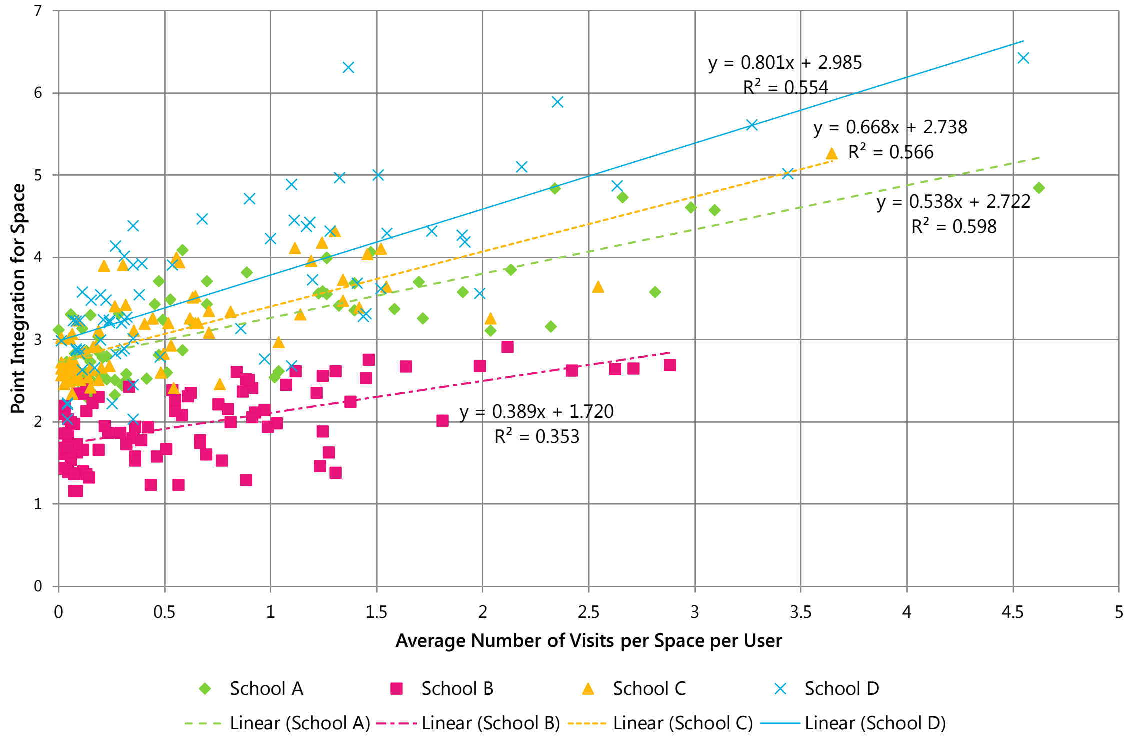



**Figure 13.1 – Scatterplot showing the relationship between the average space integration and the average number of visits per user, split by school. Overall $R^2$ for all schools is 0.321. Note all $R^2$ values are significant at $p<0.0001$.**

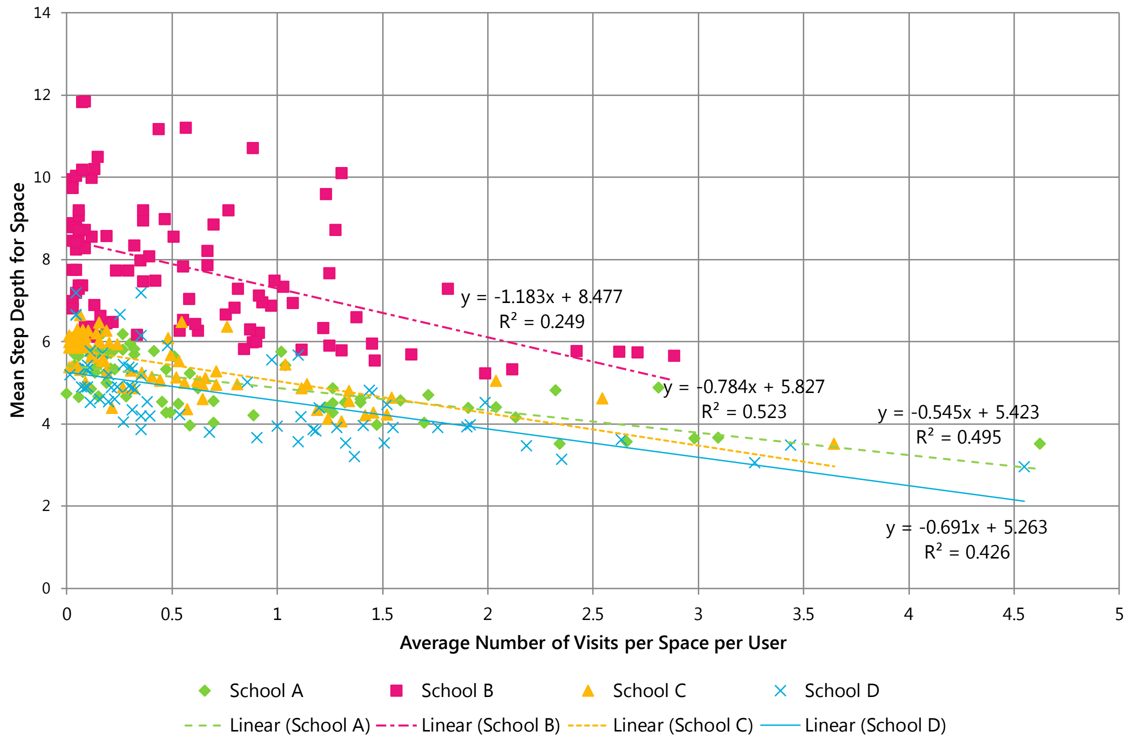



**Figure 13.2– Scatterplot showing the relationship between the mean depth and the average number of visits per user, split by school. Overall $R^2$ for all schools together is 0.179. Note all $R^2$ values are significant at $p<0.0001$.**

For both metrics, movement within school B has a much weaker link to the movement predicted from the VGA, suggesting that as the students move through the virtual building within the ISAT, they are less guided by the configuration of the building and are moving based on a need to visit a space, following the instructions given to follow a typical a day. With the other three schools, the movement is strongly linked with the VGA metrics, accounting for between 42% and 63% of the variance observed movement in the ISAT. This strong link indicates that the movement is been guided by the physical form of the building as well the end destination.

**Table 13.1 – Table showing the correlation coefficients between the number of space visits within the ISAT and the visual integration, separated by school and space type**

| | *Correlation coefficient ($R^2$) between number of visits in ISAT and integration* | |
|---|---|---|
| | Circulation | Other Spaces |
| School A | 0.477 | 0.365 |
| School B | 0.242 | 0.253 |
| School C | 0.311 | 0.494 |
| School D | 0.360 | 0.176 |

**Table 13.2 – Table showing the correlation coefficients between the number of space visits within the ISAT and the mean depth, separated by school and space type**

| | *Correlation coefficient ($R^2$) between number of visits in ISAT and mean depth* | |
|---|---|---|
| | Circulation | Other Spaces |
| School A | 0.341 | 0.300 |
| School B | 0.152 | 0.143 |
| School C | 0.276 | 0.376 |
| School D | 0.287 | 0.115 |

Given that the instructions for using the ISAT, both verbal and written, asked for the students to follow a typical day through their school, it could be expected that there is a different driver for movement between the end destinations (classrooms for example) and the route the take. To explore this effect, the circulation spaces were separated from the rest of the building and the correlation between ISAT movement and the VGA metrics were compared (see Table 13.1 and Table 13.2). As with the overall movement, integration showed stronger correlation with the movement than visual step depth, for both circulation and no-circulation spaces. Schools A and D showed greater correlation between circulation spaces and movement than non-circulation spaces (for both metrics), whereas School C showed less correlation with circulation spaces, and school B has very similar correlation for circulation and non-circulation spaces.

## 13.2 Modelling Questionnaire Results and Environmental Data

Owing to the low return rate of questionnaires at School D, only schools A, B and C have been included in this analysis. Tables of correlation coefficients are given in Appendix G, with questionnaire codes shown in Appendix C. These coefficients represent the effect of increasing the environmental parameters on the questionnaire responses, with all quoted figures significant at $p<0.05$, representing the exploratory nature of this work.

Within the questionnaire, the two questions relating to the movement through the building (questions S3aQ10 and S3aQ11) were compared to the pupil density and the mean integration. Increasing the space per pupil was shown to be positively linked to wayfinding ($\beta = 0.292$, SE = 0.005), whereas the integration was negatively correlated, although much weaker than pupil density ($\beta = -0.044$, SE = 0.024). However, the integration is highly correlated to the ease of movement ($\beta = 0.415$, SE = 0.045), with the pupil density much lower ($\beta = 0.184$, SE = 0.010).

Perceived increasing winter temperatures had strongest correlations to the external TVOC concentration ($\beta = 11.495$, SE = 1.305), and the internal/external temperature difference ($\beta = 0.191$, SE = 0.023). This is likely caused by the TVOC concentrations reflecting the pattern seen within the questionnaire rather than an association of TVOC concentrations and winter temperatures. The internal temperature did not significantly affect the perception of the winter temperatures. Feelings of being too cool were related strongly to the external temperature ($\beta = -0.195$, SE = 0.026). Warmer summer temperatures (S3bQ18) were linked to the internal temperature ($\beta = 0.251$, SE = 0.011) and the temperature difference ($\beta = 0.148$, SE = 0.005), showing a much stronger relation to recorded temperature than winter temperatures. Cooler temperatures were correlated to internal TVOC concentrations ($\beta$ = 13.410, SE = 0.280).

Air was perceived to be notably stuffier in winter (question S3bQ16) with the increasing temperature difference ($\beta$ = 0.263, SE = 0.016). Conversely, increasing concentrations of internal TVOCs ($\beta$ = -1.206, SE = 0.366) and increasing external temperatures ($\beta$ = -0.284, SE = 0.021) were linked to air quality feeling 'fresher'. A similar pattern is clear with question S3bQ17 regarding smells in winter, with slightly stronger correlations for a majority of environmental aspects. Notably, increasing internal temperature is correlated to increasing smells ($\beta$ = 0.602, SE = 0.056), and increasing TVOC is linked to decreasing smells ($\beta$ = -3.599, SE = 0.885) against expected patterns. It is likely that the TVOC concentration is mirroring an underlying pattern, with the winter air quality included in the questionnaire factor for the look and feel of the building (see Appendix E for questions included in the factors).

The NO2 difference between inside and outside conditions for all four schools was found to be negative (indicating higher concentrations outside). When combined with the negative correlation factor, it can be seen that as the difference in internal and external concentrations increases, the air quality was found to be stuffier ($\beta$ = -0.106, SE = 0.006) and smellier ($\beta$ = -0.146, SE = 0.005). As with the winter air quality, similar patterns are seen in the summer air quality perceptions, with the question on smells having stronger correlation factors than stuffiness, but both summer questions have roughly half the correlation factors of their winter questions.

Daylight factor in the classrooms was found to be negatively linked to the perceived daylight in the classrooms ($\beta$ = -28.490, SE = 4.984), reflecting the general feeling of there being too little daylight in the classrooms. This is likely linked to the extensive use of blinds in the brighter classrooms to prevent glare, with the light levels too low to measure without opening the blinds. The acoustics in the room were strongly linked with the reverberation times ($\beta$ = -11.603, SE = 0.995), with increasing times relating to more perceived distractions from noise in the classrooms, despite the difficulty for the students to perceive it.

## 13.3 Modelling ISAT results and Environmental Data

The comments from the ISAT show the perceptions of the students, but in order to fully understand these comments, the ISAT results have been compared to the measured environment.

The categorisation of the ISAT comments into properties with an occurrence value enabled the comments to be numerically analysed with the environmental data found in chapter 10. Using a binomial multi-level model, the property occurrence and the relevant environmental variable were compared to establish significant correlations. The ISAT generates two effective datasets; a positive occurrence, and a negative occurrence. Both need modelling separately to the environmental data to ensure the sentiment polarity can be captured. Environmental variables were chosen for comparison based on prior connections found within the literature review (chapter 2). A full table of results from the multilevel modelling is shown in Appendix I.

**Table 13.3 – Results of modelling ISAT air quality and temperature properties against measured environmental parameters**

| Environmental parameter | ISAT Property | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Air Quality | | | | Temperature | | | |
| | Positive | | Negative | | Positive | | Negative | |
| | β | SE | β | SE | β | SE | β | SE |
| **CO2 internal (ppm)** | * | * | * | * | * | * | * | * |
| **CO2 External (ppm)** | * | * | * | * | * | * | -0.006 | 0.002 |
| **CO2 difference (ppm)** | * | * | * | * | * | * | * | * |
| **NO2 internal (μg/m³)** | * | * | * | * | * | * | *-0.005* | *0.003* |
| **NO2 external (μg/m³)** | * | * | * | * | * | * | * | * |
| **NO2 difference (μg/m³)** | * | * | * | * | * | * | * | * |
| **PM1 Particulates (μg/m³)** | * | * | *1.600* | *0.928* | * | * | * | * |
| **PM2.5 Particulates (μg/m³)** | * | * | *1.558* | *0.898* | * | * | * | * |
| **PM10 Particulates (μg/m³)** | * | * | *1.220* | *0.713* | * | * | * | * |
| **TVOCs Internal (ppm)** | -0.040 | 0.007 | * | * | * | * | * | * |
| **TVOCs External (ppm)** | 0.091 | 0.044 | * | * | * | * | * | * |
| **TVOC Difference (ppm)** | -0.035 | 0.002 | * | * | * | * | * | * |
| **Temperature Internal (°C)** | 0.005 | 0.001 | * | * | * | * | * | * |
| **Temperature External (°C)** | * | * | 0.008 | 0.003 | *0.004* | *0.002* | 0.037 | 0.009 |
| **Temperature Difference (°C)** | 0.002 | 0.001 | * | * | * | * | * | * |

Note, figures in *italics* are significant to $p<0.05$, all other figures are significant at $p<0.01$. * indicates no significant results, and ~ indicates not tested.

Comparing the negative ISAT results with the environmental data, it is clear that the ISAT has considerably fewer links between the measured environment and the perceived environment than the questionnaire model shown in section 10.3. No significant links were found between the measured environment and either acoustics, artificial lighting, daylighting, space layout, or space size.

Table 13.3 shows that weak links were found between perceived negative air quality and the external temperature ($\beta = 0.008$, SE = 0.003), indicating that as the outside temperature increased, the negativity towards the air quality also increased. The negative comments regarding temperature were significantly positively correlated to the external temperature ($\beta = 0.037$, SE = 0.009), but negative correlations were found with the internal NO2 concentration ($\beta = -0.005$, SE = 0.001) and external CO2 levels ($\beta = -0.006$, SE = 0.002). The link between the reported negative internal temperature perceptions and the external temperature suggests that satisfaction decreases as the temperature rises, potentially indicating overheating problems. With rising internal NO2 and external CO2 levels the negative temperature perceptions decreased, but this is likely caused by a different perception of School B, which has higher values for these environmental aspects than the other three schools (see section 10.1) rather than an underlying link.

Examining the correlation between the positive ISAT responses and the measured environment, in Table 13.3, shows that perceptions of both air quality and temperature have significant links to the measured environment. The temperature is positively correlated to the external temperature ($\beta = 0.004$, SE = 0.002), corresponding to increased satisfaction as the external temperature increases at a much lower rate than the negativity increases. Satisfaction with air quality increases with the increasing internal air temperature ($\beta = 0.005$, SE = 0.001) and increasing temperature difference ($\beta = 0.002$, SE = 0.001). The internal temperature and the temperature difference are closely related, showing that as the internal temperature increases, the satisfaction increases (although no high temperatures over 26.7°C were recorded). TVOC concentrations were also important, with rising internal TVOC concentration negatively correlated ($\beta = -0.040$, SE = 0.007) and the increasing external TVOCs positively correlated ($\beta = 0.091$, SE = 0.044). External TVOC concentrations are similar at schools A, C and D, but much higher at school B (by 30.0%), indicating that the strong correlation may be singling out school B rather than an underlying link. The strong negative correlations found with the internal TVOC concentrations show a stronger sensitivity to TVOCs than to other indoor air pollutants, but it is not seen as a negative air quality issue. In all four schools, the predominant source of TVOCs were from cleaning (outside of the science lesson at School C), and any association with cleanliness may prevent it being seen as a negative air quality attribute, but instead a symbol of cleanliness.

Examining the correlation between pupil density and the ISAT building form properties (space layout, space size, and visibility), decreasing density was linked to positive space layout comments ($\beta = 0.005$, SE = 0.002), but also linked to negative comments on visibility ($\beta = -0.002$, SE = 0.001). This suggests that the additional space for each pupil may enable more appropriate layouts, but also that as there is less space there is less ability to have privacy. The intelligibility measure from the space syntax analysis has negative correlation with positive comments for space layout, space size and visibility (space size: $\beta = -0.074$, SE = 0.022; space layout: $\beta = -0.075$, SE = 0.034; visibility: $\beta = -0.062$, SE = 0.035). This strong relationship suggests that as a school building becomes more intelligible, the students become less satisfied with the built form, but necessarily negative. The integration of the building was negatively linked to positive space size ($\beta = -0.039$, SE = 0.010), positive visibility ($\beta = -0.038$, SE = 0.007) and negative visibility ($\beta = -0.017$, SE = 0.002). Correspondingly[29], the mean depth had positive correlation with positive space size ($\beta = 0.020$, SE = 0.002), positive visibility ($\beta = 0.019$, SE = 0.001) and negative visibility ($\beta = 0.007$, SE = 0.002), although the correlations were weaker. It would be expected that as the building becomes more integrated or has a reduced number of visual steps, the positivity towards the building would increase, but the opposite is true for each VGA metric. This is explained by the students singling out spaces for comment that are better than the rest of the building.

Positive comments regarding artificial lighting ($\beta = 0.493$, SE = 0.295) and daylighting ($\beta = 0.376$, SE = 0.153) were found to be positively correlated to the recorded daylight factor. The positivity is greater towards artificial lighting than the daylighting, but there is no clear explanation.

## 13.4 Modelling ISAT Results and Questionnaire Data

As the ISAT represents a different method of collecting occupant perception, it is important to compare it to a known feedback tool, in this case the questionnaire, to establish the characteristics that may assist in analysis with current and future research. Comparing the relative performance of the questionnaire (shown in Appendix C) and the ISAT, it can be seen that there is agreement in many aspects of the school environment, with the most frequently occurring ISAT properties

[29] A building with a high integration value will have a low mean step depth and vice-versa

closely matching the most significant factors from the questionnaire. Figure 13.3 shows the overlap in the factors (from section 9.2.1 and Appendix E) and property occurrence, factor one relating to the top three properties and factor two relating to the fourth and fifth properties. The significant overlap in the questionnaire factors in ISAT comments shows that the questions chosen represented the key aspects of the environment, but also shows a universality of attitude towards the environment that pervades different measures of the school.

Clearly visible in Figure 13.4 are the gaps in the factor analysis where no factor correlates to the ISAT properties. These are properties that are concerned with furniture, fittings, teaching equipment or the outside spaces, where no questions within the questionnaire captured these attitudes, but the unguided nature of the ISAT showed they were important to the students. This exposes the ease with which important issues can be missed in a complex environment.

With the low questionnaire return rate from school D, only the ISAT results at schools A, B and C have been compared to the returned questionnaires, with the results presented in Appendices J and K. Correlations coefficients are expected to be negative for negative ISAT comments and positive for positive ISAT comments, indicating the same polarity of opinions. ISAT properties have been compared to questions within the questionnaire that were identified as linked through the literature review. The generic nature of many of the ISAT properties (for example *lessons*) makes direct comparisons difficult, so only those directly linked have been undertaken to ensure that clear links can be made.

The 'General feeling' property within the ISAT had higher correlation coefficients for negative opinions than for positive, with question S3dQ28 regarding the overall building having the strongest correlation ($\beta$ = -136.673, SE = 7.965), higher than either the school or the school and building (S2Q16: $\beta$ = -79.701, SE = 6.016, S3dQ29: $\beta$ = -118.917, SE = 5.994). This is much higher than the positive correlations, with the strongest correlations found for question S3dQ29 regarding the overall attitude towards the building ($\beta$ = 19.970, SE = 0.261). The comments on 'lessons' were shown to be more correlated to the questionnaires (both negative and positive comments), with question S3dQ28 regarding overall summer conditions in the building showing particularly strong correlation ($\beta$ = -162.822, SE = 2.904). Conversely, the positive 'control of lessons' comments were shown to be especially correlated to question S2Q16 about the overall school (β = 200.951, SE = 5.942).

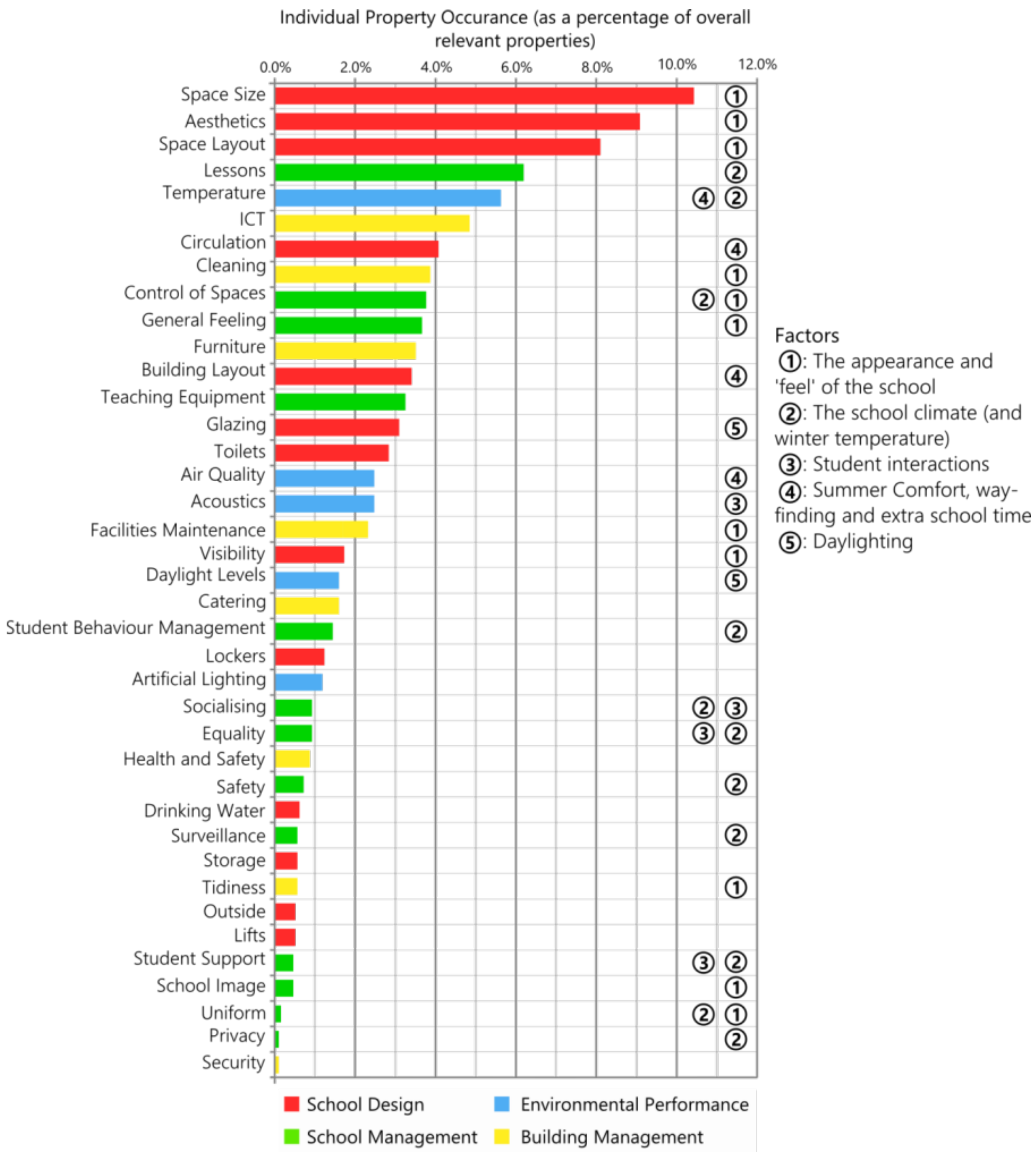



**Figure 13.3 – Dimensions found from the ISAT with the factors from the questionnaires overlaid showing the overlaps and gaps in both approaches**

Positive 'aesthetics' comments show stronger correlation than the negative, except for question S3aQ1 about pleasantness (β = 550.774, SE = 0.882), but the correlations are inverted for the positive responses. This inversion shows that while the students like the appearance, many of the positive comments were highlighting rare good aspects of the building, particularly noticeable with question S3aQ4 about personalisation (β = -19.508, SE = 2.669). This may be the reason why there was no significant correlation found for the overall aesthetics question and the positive comments.

**Table 13.4 – Results from multi-level modelling of ISAT properties and questionnaire for air quality and thermal comfort aspects of the built environment.**

| Questionnaire Question | ISAT Property | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Positive | | | | Negative | | | |
| | Temperature | | Air Quality | | Temperature | | Air Quality | |
| | β | SE | β | SE | β | SE | β | SE |
| **Winter Temperature** | ***-24.981*** | ***5.871*** | ***303.758*** | ***36.667*** | ***-3.142*** | ***0.644*** | ***-25.100*** | ***7.518*** |
| **Winter Air Quality (stuffy/fresh)** | ~ | ~ | *29.038* | *13.192* | ~ | ~ | ***-41.632*** | ***16.05*** |
| **Winter Air Quality (smelly/odourless)** | ~ | ~ | ***205.931*** | ***20.744*** | ***1.083*** | ***0.414*** | ***-26.903*** | ***7.976*** |
| **Summer Temperature** | ***4.528*** | ***1.253*** | ***32.358*** | ***2.285*** | ~ | ~ | ***-28.820*** | ***4.073*** |
| **Summer Air Quality (stuffy/fresh)** | ~ | ~ | ***58.375*** | ***12.988*** | ~ | ~ | ~ | ~ |
| **Summer Air Quality (smelly/odourless)** | ~ | ~ | ~ | ~ | ~ | ~ | ~ | ~ |

Notes: ~ indicates no significant link found at p<0.05, those in *italics* are significant at p<0.01, those in ***bold italics*** are significant at p<0.001.

Movement and wayfinding questions were covered by ISAT dimensions circulation, control of spaces and building layout. Negative circulation comments were inverted with regards to questions S3aQ10 and S3aQ11, with positive circulation comments highly correlated to S3aQ11 (β = 63.745, SE = 2.309), indicating that negative comments were highlighting difficult areas that do not represent the norm. Positive ‘control of spaces’ comments were found to be very highly correlated to the movement and wayfinding questions (S3aQ10: β = 328.069, SE = 8.421, S3aQ11: β = 407.901, SE = 29.575). Building layout was closely linked to the negative questionnaire responses, with positive comments inverted with regards to wayfinding (β = -47.488, SE = 7.034) indicating comments were singling out good aspects of the building rather that the general attitude towards the whole building.

Table 13.4 shows that temperature and air quality comments have stronger correlation to the winter conditions than the summer conditions, with no correlation found for negative comments in summer. Positive air quality comments had high correlation to room smells in both winter and summer (winter: β = 205.931, SE = 20.744, summer: β = 128.874, SE = 10.295), and notably strong correlation with temperature (winter: β = 303.758, SE = 36.667, summer: β = 62.358, SE = 2.285). Positive temperature comments have inverted correlation with winter temperature (S3bQ15: β = -24.981, SE = 5.871), indicating that positive comments were related to feeling cooler in winter.

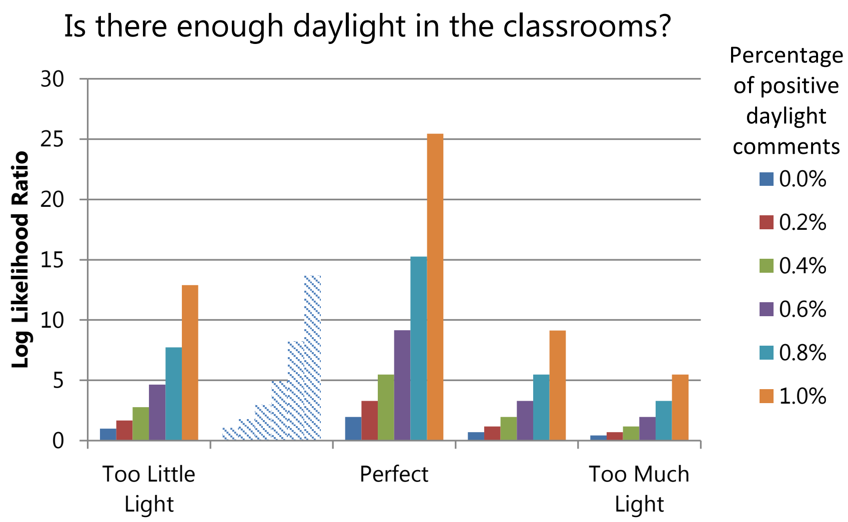



**Figure 13.4 – Likelihood of questionnaire responses for question S3cQ21, for differing amounts of positive daylight comments. Note, hatched bars indicate that model was not significant at p<0.05.**

Positive daylight comments were strongly related to increasing daylight in the classrooms (β = 255.616, SE = 11.674), with the perfect amount of light most likely to occur (see Figure 13.4). The inverted coefficient for negative comments (β = 41.502, SE = 24.683) did not produce a significant model for individual response categories, indicating that these responses were against the general trend. Positive acoustic comments are inverted for both questions S3cQ23 and S3cQ25 regarding internal noises (S3cQ23: β = -37.434, SE = 4.551, S3cQ25 β = -8.165, SE = 3.345). This suggests that the positive comments highlighted areas that were much better than the other areas.

## 13.5 Summary

Co-analysing the school level analysis has revealed links between the measured and perceived environment, bringing together a mix of qualitative and quantitative data in a robust manner. Resulting from this, several observations are possible.

*Movement through the schools follows a mix of configurational logic and attractors*

Through comparing the movement within the ISAT with the space syntax analysis, the patterns of movement were able to be analysed. School B, with its low mutual visibility, provided clear separation on quantities of movement form the other three schools (which had much higher visibility). This reduction in movement with decreasing visibility echoes the findings of Pasalar (2004), whose routes with low visibility were used less frequently. The movement in the schools within the ISAT was found to be a mix of *natural movement*, predicted by the visibility as defined by Hillier and Penn (1991), and significant *attractors*, where there were more visits despite the poor visual links to the space, as discussed by Sailer (2007). Schools A and D were shown to have more natural movement within the circulation areas than non-circulation spaces, however School C had the opposite pattern of movement, with movement to the circulation areas less predictable, likely as a consequence of the central courtyard significantly affecting movement by providing a short route between teaching wings.

*Sampled rooms with the schools have demonstrable links to the student perceptions of their whole school*

The environmental modelling hinges on the three spaces measured for week representing the whole building. By selecting rooms that had different orientations, heating and ventilation systems, and end uses, the individual effects of each type of space were mitigated. Despite the limited sampling within the schools, strong links between the internal environment and the questionnaire were found, particularly the questions on smells in winter and summer, with internal temperature the greatest influence on feelings of poor air quality. Increasing TVOC concentrations were correlated to increasing satisfaction with the air quality, suggesting that tolerance of internal environment may be linked to an underlying pattern within the school. Pupil density was also shown to have stronger correlation than mean depth when compared to navigation and ease of movement (although opposite in polarity), but both supporting the findings of Penn (2001). However, increasing intelligibility was linked to decreasing ease of wayfinding, suggesting that uniqueness of space is not as important as an intuitive layout for the students, contradicting the work of Bafna (2003).

*Binomial multilevel modelling shows that the ISAT is comparable to the questionnaire*

Strong correlation between the ISAT properties and the questionnaire were found when compared using a binomial multilevel model, with the positive responses showing stronger links than the negative responses. Positive properties of aesthetics, air quality and the control of spaces had the highest link to the questionnaire results, with the negative properties of the *general feeling* and the *lessons* themselves strongly linked to the questionnaire results. Within the environmental properties, the winter questionnaire questions had a stronger link to the ISAT properties, showing the influence of the more recent season (winter) at the time the questionnaire and ISAT were undertaken (end of spring). This exposes the unreliability of the students when remembering the internal conditions from a year ago, rather than asking them about the current conditions.

*ISAT comments are space specific and multilevel modelling with environmental data can produce misleading results*

Using the ISAT properties within the environmental performance dimension, a multilevel model explored the correlations with the measured aspects of each school. Few links were found between the various aspects of the indoor air quality and the air quality or temperature properties, although, the internal conditions were within acceptable limits on average. The correlation between some of the environmental measures (such as $NO_2$) singled out School B due to the greater difference between that school and the other three, despite the multilevel analysis compensating for the different schools. The space syntax measures found notably stronger correlations than the environmental measures taken in the three classrooms, showing the importance of taking the whole building into account rather than samples of spaces. Also apparent is the tendency of the ISAT to have correlations that indicate as conditions deteriorate (such as decreasing space per pupil) might give rise to increasing positive comments on space size. This shows that the students are able to single out spaces that they feel are better than the rest of the school and makes interpretation of raw data more complex.

*ISAT data is a complimentary tool that can be used to identify key areas of the building*

Using the ISAT has shown an additional layer of information over the more conventional methods used within this study, highlighting areas for improvement within both the questionnaires and the environmental monitoring, and providing movement patterns to explore the space syntax results. When coupled with grounded theory a pattern of importance for a school can be created, showing the key properties to be explored further. While the ISAT does record the overall sentiment of the comment, they cannot be summed to create an overall sentiment for each property, but does allow an increased focus on the important properties.

# 14 Discussion

This body of work has set out to understand the built environment of schools, examining the performance of the schools and the student perception of their environment. Given the complex interactions within the school, this research has taken a holistic mixed-method approach, creating a socio-technical approach that has been applied at both a school level and a national level. This exploratory methodology enables the macro influence of receiving a new school building to be analysed from the personal perspectives of the students within a school, illuminating the otherwise unknown actors causing changes in academic performance.

The initial step was to analyse the influence of the recent Building Schools for Future (BSF) programme through the creation of a unified school database containing key information on all secondary schools within England. Using the unified school database enabled the academic performance of schools before and after the new building to be compared, along with the influence of the internal environment and the overall energy usage to be investigated. Following this investigation into the national level trends, four case study schools were investigated using a holistic methodology that captured the internal environment (using sensors and data loggers), the built form (using space syntax), student perceptions of their school (using a questionnaire), and the unguided feedback from the students (using the Interactive Space Analysis Tool). This socio-technical approach yielded a greater understanding of the school and the environment it operates within than previously available.

This discussion section will focus on the efficacy of the ISAT as a feedback tool, the national level results compared to the school level results including the mixed methods used, the perceptions of the students of their environment, and finally the design implications of the work will be discussed. Prior to discussing the results in detail, the limitations of the applied methodology are discussed, as a key part of this research is developing a method to capture the whole school environment in a robust manner.

## 14.1 Research Limitations

This research focused on the methodology of holistically analysing the school environment from the perspective of the occupants and reconciling their opinions with the measurable environment.

As noted in the literature review, there are few studies that have attempted such a multi-faceted study and in-order to undertake such a study it necessitated some compromises that should be addressed prior to the discussion.

### 14.1.1 Small sample of BSF schools at national level analysis

The main conclusions arising from the national level study considered only 75 schools built under the BSF programme, despite over 550 being constructed. This was caused by the limited number of schools that had enough years of post-completion data available at the time of the analysis. This still forms a significant portion of the BSF schools, but only represents those school buildings that formed the initial waves of the BSF programme. As noted in the literature review, the collective knowledge on school design was low at the start of BSF due to the low number of schools built in the preceding years, however as BSF progressed it is likely that the learnings from the initial projects will have influenced the more recent designs. These buildings may have different influences on school performance that are not captured within the 75 schools analysed.

### 14.1.2 Homogeneity of design of schools at school-level analysis

The school-level analysis included four schools all designed by the same architectural practice. This was undertaken to reduce the variability within the designs, ensuring any underlying themes could be clearer during the analysis. However, this case study approach gives rise to uncertainty of results within the buildings of other architects/design teams/contractors should this study be extended to other buildings. The focus of other school design teams may be different from the chosen architectural practice, giving rise to different priorities to the students.

It should also be noted that all the schools included in the study were recently completed, with no school selected from prior to the BSF included for comparison. School building design is a continuum from the 19th century and to accurately reflect the prior school building estate would have required selections from a minimum of one school from each of the main building periods noted in the literature review. Unfortunately, limited resources prevented this from this being possible.

### 14.1.3 Questionnaire return rate

The student questionnaire was distributed within all four case-study schools, however significant numbers were only returned by three of the four schools. This limited the robustness of the multi-level analysis comparing the ISAT and questionnaire results. In addition, school D proved to be very concerned about discussions with the staff, suggesting that there were issues within the school climate. If this is the case, then it is expected the questionnaire results could have been quite extreme, potentially altering the outcomes of the factor analysis.

### 14.1.4 Student age groups

For both the ISAT and the questionnaire, only students from years 7-9 were included as the schools felt years 10 and 11 were too busy with exam preparation to spend time away from their studies. These students will be those that have potentially spent the longest in the building and consequently have different opinions on the building from the younger students. It is also not unreasonable to imagine that the older students could use the building differently and hence have different perceptions of what they need from their school building.

### 14.1.5 Engagement with wider school stakeholders

This study has focused on the opinions of the students within each school, however they represent only one aspect of the school users, overlooking for instance the teachers, administration, management, parents, and governors. Each of these groups will have a different requirement of the school building based on their differing roles, some of which may be at odds with the students. These groups may have a greater voice during the design of the building than the students and thus a greater influence over the final built environment.

### 14.1.6 Low number of spaces monitored

Within each school only three spaces were able to be monitored for one week each due to limited availability of monitoring equipment. These spaces were selected to best represent the whole building, but the variety from one classroom to the next would influence the environmental results recorded. As the students move throughout the building rather than remaining in one space, capturing a true environmental model of their experience would require a significant portion of the building to be monitored. However, an increased number of responses would improve the overall environmental picture of the school, potentially improving the results of the multi-level modelling between the measured and perceived environment.

### 14.1.7 Focus on the internal built environment only

Throughout this work, the focus of the research has been on how the built environment interacts with the school climate, but this has been limited to the internal built environment. No measurements of the external environment were included, beyond daylight availability and any views that were visible through the windows within the ISAT. The outside spaces are not only used for physical education lessons (PE) but also socialising during breaks, and hence will have an influence on the student experience of their school. This was particularly notable as an exception due to the number of comments received within the ISAT that referenced the outside or the inability to visit the outside within the tool.

## 14.2 Performance of New School Buildings at a National Level

The unified school database represented the collation of previously disparate datasets that contained data on English secondary schools, allowing longitudinal analysis of the BSF schools across a number of performance metrics. At a national-level the schools were analysed against two performance metrics; academic (attainment and absenteeism) and operational (energy). By focusing on the shift in performance between the existing building stock and the BSF buildings, the influence of the BSF programme was explored.

Focusing on the changing states of a school (moving to a new building and/or new school type) showed that where schools moved to a new building and changed type (predominantly to an academy) caused on average an improvement of 12.2% in Level 2[30] GCSE pass rate. This is higher than simply moving to a new building (a Level 2 improvement of 9.2%) or changing school type (a Level 2 improvement of 10.4%) suggesting that changing both the school and the building enables greater improvements in attainment. When examining the change in total absenteeism, only the change in building showed a significant change in absenteeism. This indicates that a new school building will significantly improve attendance, potentially through improving engagement or reducing disaffection towards the school (Kearney, 2008), although the exact reasons are not identified in this analysis. When this new school building is coupled with a changing school type,

[30] Level 2 performance is defined as % of students achieving 5 or more GCSEs at grade ‘C’ or above.

then there is greater improvement, perhaps due to the opportunity to fully utilise the new teaching pedagogies the new building allows, given that both the BSF programme and the move to academies encouraged the use of flexible teaching methods. Both Sammons et al. (Sammons, Gu, Day, & Ko, 2011) and Day and the DCSF (Day & DCSF, 2009) found that changes in leadership can have a significant impact on pupil outcomes, but when examining the BSF programme, this effect only seems to manifest itself in the Level 2 performance prior to the new building not the Level 1 attainment or the absenteeism. This may be caused by the available scale of improvement using Level 2 as a metric as opposed to Level 1, with the national average lower for Level 2 (81.8% of students achieving Level 2, compared to 93.5% of students achieving Level 1 in 2012). It should be noted that there was greater flexibility in building design within the academy programme compared to the BSF programme, which may lead to significant differences in build quality.

Using the longitudinal data within the unified school database it was possible to look at the pattern of school performance before and after the new building. A key finding from Figures 4.5, 4.6, and 4.7 is that the attainment and absenteeism improve prior to the new school building being completed (although absenteeism does not change following the move to the new building). This pattern of improvement is also seen in those school that did not receive a new building despite promises from the government (Figure 4.8) indicating that there is an aspect of the school that changes just on the promise of a new building. It is important to understand the trend in attainment before the new building seen in both the schools that received a new building and those that did not. Significant improvement in school performance can be achieved through improving leadership and changes to teaching pedagogies (Day and DCSF 2009; Sammons et al. 2011), which the additional support available from the BSF programme would have facilitated. Should there be a significant change in the leadership or teaching vision, then there could be a consequential significant change in school performance, with the well-documented effect of school leadership (Day and DCSF 2009, Seashore 2010). It is likely that as the BSF programme was envisioned as a transformation for the community and the school, it brought along a sense of hope that had a significant effect on the performance of the school (Kraftl, 2012; Webb, 2007), accounting for the improvement prior to the new building.

A disappointing finding arising from the longitudinal analysis is that the improvement caused by the BSF programme is not sustainable, with attainment performance not only ceasing to improve, but actually declining. This is somewhat concerning given that one of the core aims of the BSF programme was to improve the learning environment and thus the school performance (DfES, 2004). Given that the schools were built incorporating the contemporary design guidance (from the building bulletins), it would be expected that optimum learning environments had been achieved, which would be reflected in the performance. When read in conjunction with the improvement that occurs before the new building is constructed, it is clear that the school building process is only part of the transformation of the school. Without detailed data on the changing school climate in each school it is difficult to establish the exact underlying causes, but it may suggest that there is period where the novelty of the new building wanes with the school returning to the initial state prior to the whole BSF process.

Where building metrics were available to analyse with the school performance (BREEAM ratings, internal environmental systems, and energy usage), little evidence was found that the building influenced the outcomes of the school. Increasing energy use was shown to be weakly linked to increasing attainment, potentially as a consequence of extended hours of operation within those school with higher deprivation-weighted attainment performance. This lack of evidence of the influence of the built environment is hampered by the poor quality of data available, with a majority of the building specific data found through the DEC dataset. As discussed by Bruhns et al. (2011), a number of errors are evident within these data which are largely mitigated by the data cleaning they developed. Despite the requirement to be a trained assessor, it is difficult to establish the comparability of metrics, such as the internal environment systems, particularly where a mix of systems is evident.

In addition to questions over the validity of the building data, the performance metrics themselves need to be treated with caution. The total absenteeism figures, used due to their wide availability, showed much lower relevance to the changing school built environment than attainment and should be used with caution in future studies. Total absenteeism includes approved time away from school (such as doctor appointments or holidays) which cannot be attributed to the school climate. In addition, schools have been given greater power to restrict holidays within term time, with the ability to fine parents who take their children on holiday[31], which will have a significant

[31] See the official government website on holidays during term time: https://www.gov.uk/school-attendance-absence/overview (last accessed 13/01/2017)

influence over total absenteeism. Attainment figures within the dataset are comparatively robust for the period analysed, with little change in the GCSE programme and an open statistical analysis procedure including additional checking by the school[32].

## 14.3 Student Perceptions of Their School

At a school-level, four recently completed secondary schools were analysed from the point of view of the students, using their perspectives in tandem with the measured environment to gain a holistic understanding of how they view their school building. This was achieved using the newly developed ISAT to enable open, unguided feedback from the students while they navigate a virtual version of their building. To substantiate the data from the ISAT, this was coupled with environmental measurements and a student questionnaire. The following sections discuss the perceptions of the students, using the results of the ISAT to frame the discussions of the school environment. The data generated from the students' comments were able to be compared to the student questionnaires and the environmental measurements, enabling the limitations of each method to be explored at the same time.

### 14.3.1 Impact of the built form

The most common property from the ISAT was the space size, with many of the comments finding the space too small. In part, this reflect the visual nature of the ISAT, with students responding to an aspect they could readily interact with through the ISAT. When the perceptions of space size were modelled with the specific building measurands, no significant links were found, including for the pupil density. The pupil density used was for the whole usable floor area, but the students may have singled out certain teaching spaces that may have been particularly bad. As the schools operate in two modes; teaching and breaks (Pasalar 2007), the school buildings are used in very different modes, which have a direct bearing on how full the spaces will feel. If the all the students are confined to a small area outside of lessons, then the area will feel particularly cramped, similarly during lessons the amount of circulation space is considerably less important. With the increasing student population (see Figure 2.2) the issue of available space may become increasing important without careful management of the building and the students.

[32] See chapter 4 of the DfE Quality and Methodology report available here: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/406315/SFR02_2015_QualityandMethodology.pdf (last accessed 13/01/2017)

Within this study, there were many comments from the students relating to the lack of colour in the school, despite brightly coloured spaces being linked to improved student academic performance and positivity by Wollin and Montague (Wollin & Montague, 1981). Comparing the ISAT and the questionnaires, the inverted correlation relating to the negative comments shows that the students were singling out areas with poor aesthetics within their building; predominantly a lack of colour. This focus on the poor spaces suggests that as with Wollin and Montague's work on colour in teaching spaces, it may not be the colour that is important, but rather the lack of colour or visual interest that is detrimental. This is reinforced by the importance of the look and feel of the school found within the questionnaire, but within the ISAT the students can focus attention on particular areas.

Both the ISAT and the questionnaire did not find the circulation important as within the Barrett et al.'s study (2013) (defined as *connection* within their study). This may be largely to do with the choice of schools used by this study, with schools A, C and D dominated by their large circulation and consequently good integration (see space syntax results discussion in section 14.5.1) and the robustness of the circulation metrics used within this study. Where students used the ISAT to note spaces where they felt the circulation was good, it was typically where the circulation was generally thought to be poorer, predominantly at School B.

### 14.3.2 Indoor environmental quality

It is important to understand how the students respond to the non-visual environmental parameters within the ISAT as they are not experienced through the use of the tool. Correlation between the ISAT and the environmental aspects was less clear than those with the built form. Although temperature was the fifth highest occurring property, the link with the measured temperature was weak, with low correlation found with the increasing internal temperatures ($\beta = 0.004$, $SE = 0.002$). This might indicate some increased tolerance of higher internal temperatures, which remained relatively stable as the outside temperature increased, as predicted by adaptive thermal comfort models, such as CIBSE's TM52 (CIBSE, 2013). Some links were found with the questionnaire responses on temperature (as seen in Table 13.4), although the strongest link was the positive ISAT comments and cooler winter temperatures ($\beta = -24.981$, $SE = 5.871$). With the students required to remember the winter temperatures, it could be that the questionnaire is producing unreliable results, particularly as winter was reported as cooler, or that the action of averaging the internal conditions by the students to respond to the question creates a bias towards extremes (in this case cold temperatures).

While the temperature property had relatively weak links to the questionnaire responses on temperature, the correlation coefficients shown in Table 13.4 show that the air quality property had very strong correlation with the temperatures questions. When read in conjunction with the strong correlations between the ISAT air quality comments and the air quality questions, it is clear that the students perception of their thermal environment and IAQ is interlinked, as found by Berglund and Cain (1989) and Fang et al (1999). Measured air quality did not show many links with the reported air quality, with no links found for the $CO_2$ despite the strong evidence from previous studies (Bakó-Biró et al., 2012; Coley et al., 2007; Shendell et al., 2004) and the stipulated levels in Building Bulletin 101 (DfES, 2006). The weak links found by the ISAT to the IAQ and temperature could be a result of the comfortable conditions found within the school, notably low $CO_2$ levels, or it could be a characteristic of the ISAT particularly given the visual nature of the tool and the less tangible nature of air quality.

As with the IAQ, the ISAT daylight property was strongly linked to the daylight questions, but no links were found with the measured daylight factors. The positive comments showed a particularly strong relationship to the 'perfect' daylight questionnaire responses, and the negative ISAT comments inverted, showing the students were selecting spaces that were darker than the rest of the building. Few responses found there was too much daylight, showing the importance of the daylight in the environment. Given the visual nature of the ISAT, which is particularly evident in the top properties, the influence of the daylight would be expected to be greater, especially given the results of Heschong et al. (2002), who found increased daylight availability improved motivation in students. No comments were recorded regarding the views out of spaces, despite the strong links found by other studies (Boyce et al., 2003; Leather et al., 1998). Views out from within the ISAT were difficult to see in part due to the camera location, at the centre of the teaching spaces, and the short equivalent focal length of the camera, but also the classrooms were photographed as found with the blinds frequently closed. It is noticeable that while the students commented on other aspects they could not see, such as inaccessible rooms or the temperature, the views attracted no comments. This suggests that either the views are unimportant to the students, or that they are not aware of the views out, potentially as a consequence of the regularly closed blinds.

Acoustics within the ISAT properties had no significant links to the measured environment, either reverberation times or ambient noise levels. However, the acoustic property was linked with the questionnaire questions regarding noise from other internal areas and from within the space. Problems with acoustics were dominated by School A and the open plan teaching areas, and the inversion of the positive acoustic comments show that the students were selecting quiet spaces within the building. The strong influence of the noise from within the building supports the work of Shield et al. (2002) and Kjellberg et al. (1996) that the type of noise was important, particularly whether the noise conveys any information. Without ambient noise levels for the occupied building to compare the ISAT results against, it is difficult to confirm this, but the lack of links to the external noise may suggest some form of tolerance as discussed by Stansfield and Matheson (2003).

### 14.3.3 School climate

Notable within Figure 13.3 are the number of properties relating to the school climate, particularly the lessons property, the fourth most common property found from the ISAT. Table 14.1 shows that the lessons property was closely related to the overall attitudes towards the school found within the questionnaire. Links between the lessons and the overall attitudes towards the school were generally stronger than the general feeling property, with negative attitudes for both much stronger than the positive attitudes. The importance of the school at the classroom level over the general feeling towards the school supports Wenglinsky (2002) who suggested that the teacher quality is paramount within the school environment and Zullig et al.’s (2010) finding of the positive teacher-student relationship, rather than the school leadership as suggested by Wößmann (2003) and the Day and DCSF (2009).

**Table 14.1 – Results from multi-level modelling comparing the school climate properties of the ISAT and the questionnaire overall findings.**

| Questionnaire Question | Positive ISAT Properties | | | | Negative ISAT Properties | | | |
|---|---|---|---|---|---|---|---|---|
| | General Feeling | | Lessons | | General Feeling | | Lessons | |
| | β | SE | β | SE | β | SE | β | SE |
| **Overall, I think the school is very good.** | ***11.998*** | ***0.321*** | ***23.539*** | ***0.660*** | ***-79.701*** | ***6.016*** | ***-112.948*** | ***3.028*** |
| **Overall, the building is very good.** | ***19.406*** | ***0.296*** | ***26.308*** | ***0.822*** | ***-136.673*** | ***7.965*** | ***-162.822*** | ***2.904*** |
| **Overall, thinking about the school and the building, this school is very good.** | ***19.970*** | ***0.261*** | ***23.406*** | ***0.598*** | ***-118.917*** | ***5.994*** | ***-134.793*** | ***2.491*** |

Note: all results significant at $p<0.001$.

## 14.4 National Level versus School Level Analysis

The first part of this work focused on the creation of the unified school database, the collation of the data available on the schools within England that is within individual silos. School data has typically been collated for specific end uses, for example to illustrate attainment levels for each school, but this is largely analysed in isolation and only year by year. The creation of the unified school database is the first merging of the school specific datasets with the building performance data, achieved over a period of 13 years. This allows not only the influence of the school socio-economic backgrounds to be analysed with the performance of the building in terms of energy, but also to show the shifting trends over time that indicate the influence of a new building at a national level.

The national level study found that the BSF programme improved the attainment of the schools prior to the new building, with a steep drop-off three years after the move into the new building. With the school level analysis, the internal environments monitored were typically within the recommended parameters suggested by the building bulletins (see section 2.2), and are indicative of the other schools built under the same guidance. So if the buildings are meeting the guidance but the schools are still failing to maintain their improvement, it is clear that the attainment is linked to another more important factor of the school.

Both the ISAT and the questionnaire found that the look and feel of the school were hugely important to the students. In Duran-Narucki's work (2008), schools that were maintained well were shown to have significantly lower absenteeism, indicating that the building quality has a direct impact on the students. Rather than the impact on the students being related to a particular wall colour, the results within this research suggest any positive change to the environment is beneficial as found by Woolner et al. (2007). This is not limited to the students, but effects the whole school; heads, teachers, and support staff. Giving evidence for the Education Committee on the follow-up programme to the BSF, the Priority School Building Programme (PSBP), Seager discussed the state of his school prior to getting confirmation of a new building:

> *"…we were in appalling accommodation and were essentially a school with no future until we had a new building, because there is only so long that you can go on in impoverished accommodation. So, for all the things I have said about it, the programme has given us a future. It will see us expand. I believe that we are finding it easier to recruit staff because they are now part of something that is moving forward. You can say, 'This is the new school and these are our plans.'"* - (Seager, 2015 Q65)

Similarly, the BSF programme did not just represent a new building, but rather a transformative process for the school, perhaps bringing the hope that Kraftl (2012) discussed. This anticipation of a transformation may account for the improvement seen prior to the new school building. Within many definitions of the school climate there is always an element of motivation, usually focused on the students (Anderson, 1982; Tagiuri et al., 1968), but equally applicable to all members of staff. It may be the BSF programme acted as a reward mechanism, showing recognition for the school's work, which had a consequential positive impact on the school climate and hence the school academic performance.

The ISAT and the questionnaire both found the school climate important, particularly the lessons themselves, and the ability of a new school to transform the quality of the lessons cannot be overlooked. In practice, there is no one item of the school building that directly enabled this improvement in the school climate and lessons, but perhaps by creating a school that has a future and is cared about the occupants themselves feel motivated by proxy. As noted by Seager (2015), the very promise of a new school was enough to encourage new teachers to join the school, which could significantly improve the teaching quality. By creating a school that has the 'feel' of a successful school, it may be that schools are able to continue hiring better staff that will improve the overall school climate.

## 14.5 ISAT as a Building Analysis Tool

The ISAT represents an additional method to gather unguided occupant feedback on their environment, however as the tool is new, it is important to understand its characteristics before we can draw effective conclusions from it. Within this research we have used three well researched tools in conjunction with the ISAT; space syntax, questionnaires, and environmental measurements. These will be explored in the following sections.

### 14.5.1 Movement within the ISAT compared to Space Syntax model

Movement within the ISAT has shown to be closely related to the understood methods of movement within other studies. Students moved through their virtual building following two phenomena: natural movement (as described by Hillier and Penn (1991)) and the presence of attractors that significantly affected the movement (Sailer 2007). The sports hall, drama spaces and assembly halls in each building received far more visitors than would be expected given their integration into the school layout.

Splitting out the circulation spaces from the other spaces within the ISAT, it was found that the number of visits to the circulation spaces has stronger correlation to the integration of the spaces in schools A, C and D (circulation: $R^2$ = 0.396, non-circulation: $R^2$ = 0.297). In school B, which had the lowest correlation between the integration and the number of visits within the ISAT, the correlation coefficient is slightly higher for non-circulation spaces. With the low overall integration of the building, it appears that the building is being navigated not through vision, but rather through a need to get to certain spaces. This is trend is repeated with School C, the frequency of visits to non-circulation spaces by the students appear to be dictated by the increased visibility of the space (represented by either integration or visual step depth) rather than the timetabling by the school. This could indicate that the students using the ISAT were far more exploratory than in the other three schools.

For Schools A and D, the higher correlation between visits and circulation spaces than non-circulation spaces suggests that the non-circulation spaces acted attractors and that the students were likely following a typical day rather than exploring the school. Given the low correlation between the VGA metrics and the ISAT movement within school B, it is expected that there is little difference between the circulation and non-circulation spaces as the movement through each space is borne out of necessity to reach a destination rather visual accessibility. With School C, the frequency of visits to non-circulation spaces by the students appear to be dictated by the increased visibility of the space (represented by either integration or visual step depth) rather than the timetabling by the school. This could indicate that the students using the ISAT were far more exploratory than in the other three schools.

With the ISAT it is possible to understand whether the students were travelling to each space to make a comment about that specific space. Using a simple regression analysis, it was found that the number of comments and the number of visits within the ISAT was significantly correlated (School A: $R^2$ = 0.816, School B: $R^2$ = 0.393, School C: $R^2$ = 0.572, School D: $R^2$ = 0.408). This suggests that the students were visiting these spaces as they were important to them, in a similar manner as Sailer (2007) found in offices.

### 14.5.2 ISAT as a complimentary feedback tool

The primary use of the ISAT was to generate unguided feedback from the students at each school, creating an emergent framework that captures the specific need for that school. Using grounded theory on the ISAT results and factor analysis on the questionnaires created two independent emergent frameworks to understand the occupant feedback. While the questionnaire relied on prior knowledge to construct, in the form of Zullig et al.'s school climate (2010) and the previous environmental questionnaires (Arup, 2015; Center for the Built Environment, 2013), the ISAT had no prior framework and provided no guidance for the students. When the two results are overlaid (see Figure 13.3) it is apparent that the questionnaire and ISAT results are closely related, with the look and 'feel' of the school similarly dominating the top of both frameworks. This suggests that both are capturing the same key attitudes from the students, lending credibility to the ISAT as a robust feedback tool. This is further when examining the multi-level modelling of the ISAT and questionnaire results, with many significant links found between the two, for both positive and negative ISAT properties.

Through creating the questionnaire for the students, a number of compromises had to be made to ensure that the perceptions of as much of the school was captured without giving rise questionnaire fatigue. This necessitated the use of questions that were positively biased so that the students found them quicker to complete at the expense of leading the respondents to positive outlook. Within the ISAT there is no bias beyond the selection of spaces to be included, preventing the students being led to false positive responses. The positive ISAT responses have stronger correlation coefficients to the questionnaire within the multi-level modelling than the negative ISAT responses, except for the overall feelings towards the school.

In addition to the positive nature of the questions, the questionnaire also had to select the key areas of interest for the students based on previous surveys and the literature review. However, the ISAT showed that key areas to the students were missing, notably the furniture, fixings and equipment (including ICT), the outside spaces and the catering. Future versions of the questionnaire should include these aspects to ensure that a greater amount of the school is captured. An alternative method would be to use the ISAT as a leader in the discussions with the school prior to creating a questionnaire based on the responses, similar to a pilot study.

### 14.5.3 ISAT as an indoor environmental assessment tool

From comparisons with the measured environment, there is a clear pattern of no correlation with environmental data but good correlation to the questionnaire. The use of three spaces has not provided data that could be correlated to the perceived environment. When the occupants use the ISAT, they are generating two types of comments; general comments/feelings and comments on outliers within the school (such as unusually cold spaces), which is difficult to reconcile to the measured environment unless it is in one of the spaces measured. While the rooms were chosen to represent the building as well as possible, each space is effectively controlled locally by the teacher, opening windows, closing blinds or making requests for changes to the facilities team, and each teacher will have their own preferences Thus each space can be thought of as very independent, regardless of the location/orientation within the building. Using the ISAT before determining the spaces to be measured would enable those outlying spaces to be measured, enabling quantitative findings to be put against the perceived environment.

### 14.5.4 ISAT Limitations and Strengths

The impetus behind the creation of the ISAT was to enable large scale, unguided feedback, using the building as a guide. Through trialling the ISAT in four secondary schools, it is clear that it is capable of creating a large, rich dataset that can expose underlying themes within the school. Using techniques such as grounded theory (Corbin & Strauss, 1990), it is possible to expose the underlying themes within the data, as undertaken within this work, however future uses could use a predetermined framework to increase the speed of analysis. Fundamentally, the main dataset generated by the ISAT (the comments) is qualitative and able to be analysed by the same techniques and bound by the same time constraints as other qualitative data. However, the ISAT significantly increase the speed of data collection, effectively allowing 253 students to be interviewed regarding their school in under 12 hours, a time frame that would allow less than three minutes to interview each student using classic methods.

While the ISAT has been designed to generate feedback, it is not directly comparable to questionnaires that have been designed with the same purpose. Questionnaires, such as the BUS (Arup, 2015) and the CBE IEQ (Center for the Built Environment, 2013) use the results to create an overall score for each criterion/question, using a database of previous answers to enable robust comparisons. This relies on the respondents answering identical questions based on the same underlying analytical framework. With inherently unguided feedback from the students using the ISAT (beyond the simple introduction) direct comparisons between buildings is difficult. In addition, any scores generated from analysis, as has been undertaken here, need to respect the locality of the comments, i.e. each comment is a response to one space and not necessarily the whole building. This was evident in the comparison with the questionnaire, with respondents identifying areas that were better or worse than average. The importance of the issues within a building can be identified through counting occurrences of properties (as in Figure 13.1), but producing an overall 'score' for the building is difficult without the use of a unified framework. Additionally, it can be inferred that where no comments are received for a particular property then that particular environmental attribute may be acceptable, but this absence of data is understandably difficult to analyse robustly. Comparisons between buildings could be enabled through the use of a pre-set framework, coding comments as they fall into the categories of interest, but this would negate some of the uniqueness of the unguided feedback and raise the same issues as designing a questionnaire (the selection of appropriate areas for the specific building without missing a key element).

Using a virtual version of the building creates an ability to respond to particular design features that are beyond standardised questionnaires, but the visual nature of this tool creates a bias towards comments on the visual aspects of their building. This has typically been overlooked in post-occupancy evaluation studies, but when comparing the magnitude of the comments to understand the perception of the building, it should be recognised that there may be undue emphasis on the visual environment. Conversely, non-visual aspects of the building that are reported may be more important than they initially appear as they are not able to be captured by the ISAT.

In studies exploring how the occupant sees their building, such as within space syntax fields, this visual bias may be beneficial, particularly when coupled with the ability to record the movement through the space. The comparisons with the space syntax results shows that the navigation through the building appears to representative of defined movement patterns, enabling the ISAT to be used to analyse people movement in buildings. However, the ISAT movement needs to be verified with monitored movement from the actual buildings before it can be robustly used in place of monitored movement (as attempted by Conroy-Dalton (2001)).

## 14.6 Synthesis of Socio-Technical Methods

A key aim of this research was to utilise a holistic methodology to analyse the schools, creating a total picture of the school climate and built environment. Previous research tended to focus on individual aspects of the school or the built environment, such as air quality, and drawing conclusions on the impact of the individual aspect on the school, overlooking interactions that may exist between each of the aspects of the school climate and built environment. Through creating this holistic methodology, not only could the whole school environment and climate be co-analysed, but also the overlaps and gaps that exist within each individual methodology could be exposed.

Within this research, five analysis tools have been used, with each tool adding to the totality of the analysis, as shown in Table 12.2. The quantitative section of the methodology was able to capture nearly all aspects of the school through the selection of the three tools (Unified School Database, space syntax, and environmental measurements) with only the school climate eluding the analysis. The school climate is a personal connection between the student and their school, with groundings in the quantitative, measurable aspects of the school, but ultimately formed from their interaction with the school. Across the 13 school aspects captured, only three aspects are captured by more than one tool; building layout, energy consumption and outdoor spaces. The building layout is the only aspect measurable by all three quantitative tools, although the unified school database is only able to capture the basic floor area of a school. This lack of overlap shows the importance of using mixed methods to ensure that the whole school is measures, although it should be noted that the outdoor spaces were not investigated, but have been included due to their importance within the ISAT responses.

Of the two qualitative methods used, the questionnaire is able to capture more aspects of the school, with the ISAT unable to include academic performance or the socio-economic background. Within this study, no questions were asked regarding these two points as they are personal and risk alienating the students. In addition, by increasing the number of questions there is a greater risk of questionnaire fatigue, with answers towards the end becoming less reliable. While the ISAT is not able to capture the same perceptions as the questionnaire, by producing an unguided feedback tool, the respondent is able to give their opinion on 10 of the 13 aspects, without the risk of questionnaire fatigue. Neither a questionnaire or the ISAT were able to capture the energy use of the school, although patterns of usage might be discernible from carefully worded questions within a questionnaire.

**Table 14.2 – Table showing the ability of each tool used to capture the specific elements of the school climate and built environment identified within the literature review and through the research**

| School Aspect | Analysis Tool | | | | |
|---|---|---|---|---|---|
| | *Quantitative* | | | *Qualitative* | |
| | Unified School Database | Space Syntax | Environmental Measurements | Questionnaire | ISAT |
| Academic Performance | ✓ | | | ✓‡ | |
| Acoustics/noise | | | ✓ | ✓ | ✓ |
| Aesthetics | | | ✓ | ✓ | ✓ |
| Building Layout | ✓* | ✓ | ✓‡ | ✓ | ✓ |
| Daylight | | | ✓ | ✓ | ✓ |
| Energy consumption | ✓ | | ✓†‡ | | |
| Furniture, fittings and equipment | | ✓** ‡ | | ✓ | ✓ |
| Indoor Air Quality | | | ✓ | ✓ | ✓ |
| Movement/wayfinding | | ✓ | | ✓ | ✓ |
| Outdoor spaces | | ✓‡ | ✓‡ | ✓‡ | ✓ |
| School Climate | | | | ✓ | ✓ |
| Socio-economic background | ✓ | | | ✓‡ | |
| Temperature | | | ✓ | ✓ | ✓ |

*Notes: * - The unified school database contains data on the gross internal floor area only.*
*** - Space syntax can analyse the layout of the FF&E, but not the FF&E itself.*
*† - While not a true environmental measure, energy can be recorded in a building using data loggers.*
*‡ - Indicates an aspect of the school that was not assessed using the specific tool, but could be.*

Comparing the qualitative and quantitative tools, there are only two aspects that are not measured by both subsets of tools; the energy consumption and the school climate. As noted above, the school climate is inherently qualitative, representing the opinions of the students, while the energy performance is predominantly too technical for the students to provide reliable feedback. Within each of the other 11 aspects, there is the ability to measure the physical parameters of the school and compare them to the perceptions of the students, enabling the connections between the two to be explored. In particular, the three tools used to measure the quantitative aspects had little overlap, so without using all three would have left considerable gaps within the holistic analysis.

Bringing together the quantitative and qualitative datasets requires complex multi-level modelling and specialist statistical software to ensure that the data analysis is robust. These techniques are a significant barrier to wider usage, but with the availability of MlwiN (Rasbash, Charlton, et al., 2014) and the increasing usage of multi-level modelling within research, the skills needed are becoming more available. However, it should be noted that both the ISAT and the questionnaire require more complex forms of multi-level modelling; binomial and multinomial versions.

## 14.7 Trends in Student Perceptions

Through capturing the measured environment and the perceived environment, it is possible to explore the way in which students think about their environment, establishing concepts that will enable future research into the school built environment

Comparing the perceived IAQ (both ISAT and questionnaire) to the measured pollutants, the questions regarding smells had stronger correlations than those questions regarding freshness. The clarity of wording undoubtedly helped the stronger correlations, with smells an easily comprehendible concept, whereas freshness is a less clear. This is also true when comparing the different perception data, with the ISAT air quality having a higher correlation with the smells than the freshness in the questionnaire responses. Also notable is the air quality perceptions had greater correlations to the indoor temperature than the perceived temperature, suggesting that temperature is more readily discernible than thermal comfort. This is also true when comparing the ISAT and questionnaire perceptions. This is unexpected as temperature is more widely known, but may indicate that problems with air quality are indicators of other internal environmental quality issues.

Given the strong emphasis on the look of the building from the questionnaire and ISAT results, the strong link between the two is expected. Questions on specific aspects of appearance, maintenance, and cleaning were all strongly correlated (see Appendices J and K), with stronger correlations to the positive comments, although nearly all are negatively correlations (except pleasantness and maintenance). These negative correlations suggest, as discussed before, that the students are selecting exceptions to their overall perceptions of the school, selecting good areas. The two positive correlations, for the pleasantness and maintenance, show the ease with which students perceive these areas and the wording within the questionnaire. These strong student perceptions of the aesthetics and maintenance provide an explanation to the strong links found by Durán-Narucki (2008) and the influence of colour within the school (discussed by Woolner et al. (2007)). If these aspects of the environment are the most tangible aspects of the environment, any improvement is likely to have the greatest influence over the students, including their attitude towards the school.

A recurring theme through the multilevel modelling comparing the ISAT to the questionnaire and the environmental measures is the positive ISAT responses had stronger correlations than the negative comments. Based on this, the students seem to be able to give a more accurate view on their environment when they are being positive, whereas negative comments seem to be less representative of the building as a whole. This is likely caused by the students singling out areas that are worse than average (as noted above) but it also suggests that those comments are more likely to be made by those more extreme views of the school and need to handled carefully to ensure a balanced view of the school is formed.

The multilevel modelling enabled the separation of the influence of the school from the direct influence of the measured environment on the perceptions of the school. Despite the statistical separation of the school, the influence of the school was still evident where there was a distinct pattern within the measured environment and the perceived environment. This is clearest when examining the influence of the external TVOC concentration on the perceived internal air quality, with increasing concentration suggesting greater satisfaction. This is counter to the literature on the impact of the TVOC on the school environment (Chatzidiakou et al., 2012a; Mendell & Heath, 2005; Otto et al., 1992) and shows a limitation of the small number of case studies used. However, it does show the influence of the school climate on the overall perception of the students on their school building, with School B having the highest external TVOC, but also the greatest overall impression of the school climate (see Appendix D). Within a majority of the definitions of the school climate (for example Tagiuri et al., 1968; Zullig et al., 2010) there is an element of the building environment, showing the integral part the building plays in the overall school climate. This link between the building and the school climate is also seen within the factor analysis, with the school climate factor also including aspects of the building (temperature and wayfinding).

From the underlying patterns connecting the school climate and the built environment, it suggests that the students are unable to separate the building from the school. In studies attempting to evaluate the perceptions of students of their school, it is important to control for their overall attitude towards their school. Without controlling for the overall satisfaction of the students with their school, any perceptions inferred for aspects of the built environment is likely to be significantly affected by their connection to the school.

## 14.8 Implications on Building Design

As discussed throughout this paper, schools need to respond to their specific environment, however, from this work there are distinct building design features that had an impact on the overall school.

### 14.8.1 Building Aesthetics

The appearance of the building had a clear impact on the students, and potentially the staff. The schools should present themselves as the dynamic institutions that they are, utilising bold colours to create a strong sense of identity, as shown by Wollin and Montague (1981). By utilising student work to decorate the building, this dynamism can be created while forging a greater link with the school building. The use of student art was noted in School D which had the most positive comments regarding the aesthetics of the building. By building an identity of the school from the student work it could help to bring colour into the building and build greater pride/affinity with the school.

### 14.8.2 Size and Flexibility of Teaching Spaces

Within the ISAT, the size and layout of the teaching spaces were clearly very important to the students. Given the importance of the teachers on the success of the school, the focus on the classroom itself is not surprising. By creating teaching spaces that are flexible, the teachers can set the room up to suit their individual teaching needs/style, which was shown to have significant impact on their performance (Martin, 2002; Sime, 1985, 1986). Flexibility is incredibly important, and this can be greatly assisted by having space to enable many different classroom configurations. Given the predicted increase in student numbers (Figure 2.2) and with the limited ability to create new schools, the space within classrooms may become effectively smaller as class sizes increase. Building in this additional space within the classrooms will not only assist with current classroom flexibility, but ensure future flexibility, potentially creating greater value for money in the long term, with reduced requirement for alterations in the future.

### 14.8.3 Thermal Comfort

Temperature was important in all four schools, with the students noting that they felt the spaces were too warm. Thermal comfort is a very tangible aspect of the environment and within schools the high density of internal heat gains (ICT and the students) means it should be a key design driver within the classrooms. Given the predicted rise in temperatures due to global warming, this is only going to become more of an issue in future as the ambient air temperatures rise. Designs should be incorporating passive designs that are able to reduce temperatures of the teaching spaces, even with the future increases in global temperature. While the classrooms were felt to be too warm by the students, the communal areas were often felt to be cold, particularly at School A where the large central atrium was regularly noted by the students as being too cold. As students may spend considerable time within these zones at breaks, these spaces should be subject to the same thermal comfort standards as the other spaces.

### 14.8.4 Noise and Acoustics

The acoustic environment of the school is clearly very important, but as found by Shield et al. (2002) and Kjellberg et al. (1996), the type of noise is hugely important. The students within this study did not perceive noise from outside the school to be a problem, however noise from within the school was found to be very distracting. The open plan teaching spaces at School A were found to be particularly problematic, with noise transferring easily between spaces. Due to space constraints in dining halls, staggered breaks were necessary at Schools C and D, with consequential noise a source of distractions. Partitioning the school into areas for socialising and areas for teaching, such as through teaching wings, can be an effective solution. At School B, the number of floors assisted in reducing noise from the breaks/lunch reaching the classrooms, with the dining area situated on the ground floor away from a majority of the teaching rooms.

# 15 Conclusions

This work set out to explore the impact of the built environment within a school context. To facilitate this, a two-level study was undertaken, with a national level study capturing the performance of all secondary schools in England, and a school level study evaluating the influence of the built environment on the school. Note that a discussion of the limitations is found in section 14.1.

## 15.1 Principal Conclusions

Through the two-level study, four principle conclusions have been found:

*A socio-technical, mixed-method approach allows deep understanding of the student perception of their environment.*

This study created a mixed-method approach to understand the whole school, with each tool either exposing another aspect that would not be otherwise analysed or provided an additional level of information on that aspect. The mixture of national level and school level analyses allowed the influence of the built environment and school climate to be seen against a backdrop of national trends. Multi-level modelling of the data effectively analysed the links between the measured environment and the perceived environment, correlating how the students view their environment and how it can be measured. Use of the space syntax tools put a value to the building form that was not traditionally possible beyond simple metrics (such as floor area), enabling not only an understanding of the movement within the ISAT, but also how the students perceive the layout of their school. This analysis showed that the students are able to understand much of their built environment, including air quality, temperature, acoustics, daylight and aesthetics. However, the school climate has a significant impact on their tolerance of the environmental parameter, with greater affinity for the school leading to greater tolerance.

*A new school building produces a temporary boost to school attainment*

Using the unified school database, the performance of schools that received a new building under the BSF scheme were shown to improve prior to the move into the new building. However, for a majority of schools this improvement was short-lived following the move, with attainment results returning to a similar level prior to the new school building process. This improvement prior to the new school, and despite the disruption of a neighbouring building site at many of the schools suggests that the new building is not the true cause of the improvement, but instead some part of the process is the real cause for the improvement. It is hypothesised that the creation of a new school building gives the school a sense of hope, inspiring the school and attracting new teachers who improve the performance of the school, before the novelty wears off and the school returns to its prior state.

*The look and feel of the school was the most important aspect of the school*

Through the factor analysis of the student questionnaire and the grounded theory analysis of the ISAT comments, the look and feel of the school emerged as the key underlying theme in the student perception of their environment. This included colour, personalisation, aesthetics, space size, space layout, and cleanliness. A key theme is that the school should be something the students are proud of, with the look and feel of the school integral to how they perceive the school. Any detractions from the school were noted by the students, particularly issues such as lack of colour, poor maintenance or untidy areas. These can undermine the image of the school and prevent the student from feeling the same level of affinity with the school.

*Use of the ISAT allows large scale unguided feedback from building occupants*

The ISAT was developed to achieve widespread feedback in an unguided manner, through creating a virtual version of the school. This tool has enabled 253 students to give feedback on a wide variety of building issues, including those that were overlooked using conventional methods. By using the comments from the ISAT in conjunction with grounded theory, the underlying patterns of student perception was uncovered, with those aspects that were most commonly mentioned the most important to the student by way of their unforced nature. In future building research projects, the ISAT could be a valuable tool at the start of the project, giving an overview of not only the key aspects of the built environment, but also the location of these key aspects within the building. A considerable bonus is that the ISAT allowed the students to give feedback on the school as well as the building, showing how the two entities are deeply entwined in their perceptions.

## 15.2 Progress Against Research Questions

At the start of this research, four distinct questions were asked to improve the knowledge of the impact of school design. A summary of progress against these questions is presented below.

*How do student perceptions of the built environment interact with the measured environment?*
Through using the ISAT and questionnaire to capture the perceptions of the students at four case study schools, and using multi-level modelling to compare these to the measured environmental aspects, the underlying patterns of perception were investigated. Links were shown between the measured temperature, air quality, acoustics, built form and daylight.

*What is the impact of a new building school performance?*
Using the unified school database the attainment, absenteeism and energy performance of school receiving new buildings under the BSF programme was explored. It was found that new buildings created an improvement in attainment and absenteeism prior to the new building being completed, with improvements in absenteeism only lasting for three to four years after the move to the new building. This temporary improvement suggests that the new building is a catalyst for change within the school that is not necessarily sustainable. When examining the energy use, it was found that use was higher in new BSF schools, while the heating was lower, with overall no significant difference in total energy use.

*What are the most important aspects of the built environment to the students within their school?*
The ISAT enabled the students to only comment on aspects of the building that were the most important to them. This found that the look and feel of the school was the most important aspect of the school environment, with temperature also rated highly. When using the questionnaire the look and feel of the school were also shown to be the most important aspects of the building environment.

*What are the implications on future school design arising from the exploratory methods used within this study?*
Using the results of the multi-level method four suggestions for future school design have been suggested; focus on building aesthetics, improve the size and flexibility of the teaching spaces, improve thermal comfort throughout the school, and reduce nuisance noise. Much of the school

improvement appears linked to the look and feel of the school, with a school that projects a successful image likely to improve performance.

## 15.3 Future Work

This work answered the research questions initially set out, however the highly explorative nature of this work has opened avenues for further research using the research methods that have been developed. The following recommendations for future research are suggested in each section.

**Expanded School Case-Studies**

The school-level study focused on four schools designed by the same architect. However, these schools are not necessarily representative of the whole population of new school buildings, with each design team putting their own experience into the school designs. Future studies should apply the methodology of this work to explore whether the findings from these schools equally apply to other schools built under the same design drivers. Additionally, a majority of schools are not new, but instead from earlier eras of school design. Applying the same methodology to older school designs may expose a greater understanding of the how the school environment is perceived, particularly using the ISAT which is able to capture the attitudes towards the built form.

**Increased Environmental Monitoring**

In this study, the perceived environment was well represented, however the environmental monitoring of the schools was only for a relatively short period and only in three spaces. The perceived environment was found to have limited connection with the perceived environment, but due to the limited monitoring possible, it is not possible to quantify the environment that gives rise to the measured perceptions. A follow study with increased monitoring would be hugely beneficial, clarifying the levels at which the students within a school perceive certain aspects of the environment.

**Expansion of the Unified School Database**

The unified school database proved to be useful in assessing the performance of schools longitudinally. Schools do not stop developing and this database provides a robust method of evaluating this continuous development. Other measures of school performance that were relatively recent, such as student improvement measures, can also be incorporated to enable greater comparison between the schools. In addition, England is not the only country to have a large school building programme, and this study would be just as important in other countries, such as Portugal and Australia.

**Inclusion of Staff within Methodology**

Throughout the school-level study, the emphasis has been on the students' perception of their environment, however the staff are an integral part of the school and future studies should aim to incorporate them into the methodology. While the students can be thought of as the output of the school, understanding the staff attitudes will enable future research to understand the origins of the student attitudes and produce a fuller picture of the school climate.

**Verification of the ISAT Movement**

The space syntax analysis of the ISAT showed that the movement followed known patterns within the space syntax community, which would increase the future viability of the ISAT as a useful tool for future research. However, no movement of students within the buildings was recorded, limiting the conclusions that can be drawn from the space syntax analysis. Future work should undertake the ISAT within a building while also measuring the movement of the students within the space. Comparing the movement between the real building and the virtual building will provide an important insight into the use of the ISAT.

**Use of Socio-Technical methods within non-educational setting**

This work has focused on the school environment, but the same techniques could be applied to other non-domestic settings (e.g. offices) as well as domestic buildings. The principles of the ISAT could easily be scaled up to be used within larger spaces, such as housing developments, enabling wider community impacts of the built environment to be captured, similar to the studies by Moore et al. (2008) and Adams et al. (2007).

# 16 Bibliography

Adams, M., Moore, G., Cox, T., Croxford, B., Refaee, M., & Sharples, S. (2007). The 24-hour City: Residents' Sensorial Experiences. *The Senses and Society*, *2*(2), 201–215. http://doi.org/10.2752/174589307X203092

Ahrentzen, S., & Evans, G. W. (1984). Distraction, privacy, and classroom design. *Environment & Behavior*, *16*(4), 437–454. http://doi.org/10.1177/0013916584164002

Amaratunga, D., Baldry, D., Sarshar, M., & Newton, R. (2002). Quantitative and qualitative research in the built environment: application of "mixed" research approach. *Work Study*, *51*(1), 17–31. http://doi.org/10.1108/00438020210415488

Anderson, C. S. (1982). The Search for School Climate: A Review of the Research. *Review of Educational Research*, *52*(3), 368–420. http://doi.org/10.3102/00346543052003368

Appleton, J. J., Christenson, S. L., & Furlong, M. J. (2008). Student engagement with school: Critical conceptual and methodological issues of the construct. *Psychology in the Schools*, *45*(5), 369–386. http://doi.org/10.1002/pits.20303

Arup. (2015). BUS Methodology: BUS methodology - Occupant Satisfaction Evaluation. Retrieved September 7, 2015, from http://www.busmethodology.org/

ASHRAE. (2011). *Interactions affecting the achievement of acceptable indoor environments*. Atlanta, GA: American Society of Heating, Refrigerating and Air Conditioning Engineers.

ASHRAE. (2013). *Standard 55-2013. Thermal environmental conditions for human occupancy*. Atlanta, GA: American Society of Heating, Refrigerating and Air Conditioning Engineers.

Association of Noise Consultants. (2011). *ANC Good Practice Guide: Acoustic Testing of Schools* (Version 1.). Retrieved from http://www.association-of-noise-consultants.co.uk/ViewFile/Id/326ba9907fb7eea6c5ee3ae7f2ed6d64a7434504

Attwood, G., & Croll, P. (2006). Truancy in secondary school pupils: prevalence, trajectories and pupil perspectives. *Research Papers in Education*, *21*(4), 467–484.

http://doi.org/10.1080/02671520600942446

Bafna, S. (2003). Space Syntax: A Brief Introduction to Its Logic and Analytical Techniques. *Environment & Behavior*, *35*(1), 17–29. http://doi.org/10.1177/0013916502238863

Bakó-Biró, Z., Clements-Croome, D. J., Kochhar, N., Awbi, H. B., & Williams, M. J. (2012). Ventilation rates in schools and pupils' performance. *Building and Environment*, *48*, 215–223. http://doi.org/10.1016/j.buildenv.2011.08.018

Barrett, P., Zhang, Y., Moffat, J., & Kobbacy, K. (2013). A holistic, multi-level analysis identifying the impact of classroom design on pupils' learning. *Building and Environment*, *59*, 678–689. http://doi.org/10.1016/j.buildenv.2012.09.016

Beatty, P. C., & Willis, G. B. (2007). Research Synthesis: The Practice of Cognitive Interviewing. *Public Opinion Quarterly*, *71*(2), 287–311. http://doi.org/10.1093/poq/nfm006

Ben-Akiva, M. E., & Lerman, S. R. (1985). *Discrete Choice Analysis: Theory and Application to Travel Demand*. MIT Press. http://doi.org/10.2307/1391567

Berglund, L., & Cain, W. (1989). Perceived air quality and the thermal environment. In *IAQ '89 - The human equation: Health and comfort proceedings* (Vol. 89, pp. 93–99). Retrieved from http://www.inive.org/Ibase_search/search-detail-airbase-001.asp?ID=4207

Berman, S., Navvab, M., Martin, M., Sheedy, J., & Tithof, W. (2006). A comparison of traditional and high colour temperature lighting on the near acuity of elementary school children. *Lighting Research and Technology*, *38*(1), 41–52. http://doi.org/10.1191/1365782806li155oa

Betoret, F. D., & Artiga, A. G. (2004). Trainee teachers' conceptions of teaching and learning, classroom layout and exam design. *Educational Studies*, *30*, 355–372. http://doi.org/10.1080/0305569042000310309

Boubekri, M., & Haghighat, F. (1993a). Windows and Environmental Satisfaction: A Survey Study of an Office Building. *Indoor and Built Environment*, *2*(3), 164 –172. http://doi.org/10.1177/1420326X9300200305

Boubekri, M., & Haghighat, F. (1993b). Windows and Environmental Satisfaction: A Survey Study of an Office Building. *Indoor and Built Environment*, *2*(3), 164–172. http://doi.org/10.1177/1420326X9300200305

Boyce, P., Hunter, C., & Howlett, O. (2003). The Benefits of Daylight through Windows. *Lighting Reasearch Center*, *1*(1), 1–88. http://doi.org/12180-3352

BRE. (2013). BREEAM: the world's leading design and assessment method for sustainable buildings. Retrieved August 19, 2013, from http://www.breeam.org/

British Standards Institution. (2009). *BS EN ISO 3382-2:2008 Acoustics - Measurement of room acoustic parameters - Part 2: Ordinary Room* (Vol. 3). BSI. Retrieved from https://bsol-bsigroup-com.libproxy.ucl.ac.uk/Download/SubscriptionPdfDocument?materialNumber=000000000030203285

British Standards Institution. (2012). *BS EN ISO 16283-1, Acoustics - Field measurement of sound insulation in buildings and of building elements - Part 1: Airborne sound insulation* (Vol. 3). BSI. Retrieved from https://bsol-bsigroup-com.libproxy.ucl.ac.uk/Download/SubscriptionPdfDocument?materialNumber=000000000030301090&documentNumber=BS EN ISO 16283-1%3A2014

Bruhns, H., Jones, P., & Cohen, R. (2011). *CIBSE review of energy benchmarks for display energy certificates - Analysis of DEC results to data*. Retrieved from http://www.cibse.org/content/Technical_Resources/Technical_Reports/Technical Report_CIBSE Report on 45000 DECs.pdf

Center for the Built Environment. (2013). Center for the Built Environment: Occupant Indoor Environmental Quality (IEQ) Survey. Retrieved February 4, 2015, from http://www.cbe.berkeley.edu/research/briefs-survey.htm

Chatzidiakou, E., Mumovic, D., Summerfield, A. J., & Altamirano, H. M. (2014). Indoor air quality in London schools. Part 1: "performance in use." *Intelligent Buildings International*, *0*(January 2015), 1–29. http://doi.org/10.1080/17508975.2014.918870

Chatzidiakou, L., Mumovic, D., & Summerfield, A. J. (2012). What do we know about indoor air quality in school classrooms? A critical review of the literature. *Intelligent Buildings International*, *4*(4), 228–259. http://doi.org/10.1080/17508975.2012.725530

Chatzidiakou, L., Mumovic, D., Summerfield, A. J., Tàubel, M., & Hyvärinen, A. (2014). Indoor air quality in London schools. Part 2: long-term integrated assessment. *Intelligent Buildings International*, *0*(January 2015), 1–17. http://doi.org/10.1080/17508975.2014.918871

CIBSE. (2006). TM 41: Degree-days: Theory and application. *Chartered Institute of Building Services Engineers, London*.

CIBSE. (2007). *Environmental Design - CIBSE Guide A* (7th ed.). CIBSE.

CIBSE. (2008). *TM 46 Energy Benchmarks*. CIBSE Publications, London.

CIBSE. (2009). *TM 47: Operational ratings and display energy certificates*. (H. Davies, Ed.). London: CIBSE.

CIBSE. (2013). *The limits of thermal comfort: avoiding overheating in European buildings*. London: The Chartered Institution of Building Services Engineers.

Clapp, L. J., & Jenkin, M. E. (2001). Analysis of the relationship between ambient levels of O3, NO2 and NO as a function of NOx in the UK. *Atmospheric Environment*, *35*(36), 6391–6405. http://doi.org/10.1016/S1352-2310(01)00378-8

Clegg, P. (2015). *Learning from Schools*. Artifice Books on Architecture. Retrieved from https://books.google.co.uk/books?id=ly-ErgEACAAJ

Cohen, J. (1992). A power primer. *Psychological Bulletin*, *112*(1), 155. Retrieved from http://psycnet.apa.org/journals/bul/112/1/155/

Coley, D. A., & Beisteiner, A. (2002). Carbon dioxide levels and ventilation rates in schools. *International Journal of Ventilation*, *1*(1), 45–52. http://doi.org/10.5555/ijov.2002.1.1.45

Coley, D. A., Greeves, R., & Saxby, B. K. (2007). The effect of low ventilation rates on the cognitive function of a primary school class. *International Journal of Ventilation*, *6*(2), 107–112. http://doi.org/10.5555/ijov.2007.6.2.107

Collett, D. (2003). *Modelling Binary Data* (2nd ed.). New York: Chapman & Hall/CRC.

Collins, C. W., Kenway, J., McLeod, J., Australia, & Department of Education, T. and Y. A. (2000). *Factors influencing the educational performance of males and females in school and their initial destinations after leaving school.* [Canberra]: [Commonwealth Dept. of Education, Training and Youth Affairs]. Retrieved from http://www.dest.gov.au/NR/rdonlyres/F0270F6E-B2C3-4CF4-833D-4C8029EA7D6E/4093/Gender_Report.pdf

Conroy-Dalton, R. (2001). Spatial Navigation in Immersive Virtual Environments. *Unpublished PhD Thesis*, *PhD*(January), 249. Retrieved from http://discovery.ucl.ac.uk/1111/

Corbin, J. M., & Strauss, A. (1990). Grounded theory research: Procedures, canons, and evaluative criteria. *Qualitative Sociology*, *13*(1), 3–21. Retrieved from http://link.springer.com/article/10.1007/BF00988593

Cotterell, J. L. (1984). Effects of School Architectural Design on Student and Teacher Anxiety. *Environment and Behavior*, *16*(4), 455–479. http://doi.org/10.1177/0013916584164003

Crandell, C. C., & Smaldino, J. J. (2000). Classroom Acoustics for Children With Normal Hearing and With Hearing Impairment. *Language, Speech & Hearing Services in Schools*, *31*(4), 362–370. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=a9h&AN=3737758&site=ehost-live

Csobod, É., Annesi-Maesano, I., Carrer, P., Kephalopoulos, S., Madureira, J., Rudnai, P., … Viegi, G. (2014). *SINPHONIE – Schools Indoor Pollution and Health Observatory Network in Europe - Final Report*. http://doi.org/10.2788/99220

David A. Coley, & Beisteiner, A. (2011, February). Carbon Dioxide Levels and Ventilation Rates in Schools. http://doi.org/10.5555/ijov.2003.1.3.181

Day, C., & DCSF. (2009). *The impact of school leadership on pupil outcomes: final report*. [London]: Dept. for Children, Schools and Families. Retrieved from http://dera.ioe.ac.uk/11329/1/DCSF-RR108.pdf

DCLG. (2008). *A guide to Display Energy Certificates and advisory report for public buildings.*

Communities and Local Government Publications. Retrieved from http://webarchive.nationalarchives.gov.uk/20120919132719/http://www.communities.gov.uk/documents/planningandbuilding/pdf/20.pdf

Department for Education. (1999). *Lighting design for schools*. London: Stationery Office. Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/276707/Building_Bulletin_90_lighting_design_for_schools.pdf

Desforges, C., & Abouchaar, A. (2003). The Impact of Parental Involvement , Parental Support and Family Education on Pupil Achievements and Adjustment : A Literature Review with. *Education*, *30*(8), 1–110. http://doi.org/10.1016/j.ctrv.2004.06.001

DfE. (n.d.-a). Edubase Public Portal - Home. Retrieved November 23, 2012, from http://www.education.gov.uk/edubase/home.xhtml;jsessionid=3B8978559776F84D11A95649557DBC86

DfE. (n.d.-b). Performance Tables - The Department for Education. Retrieved July 25, 2013, from http://www.education.gov.uk/schools/performance/index.html

DfE. (n.d.-c). The 1870 Education Act. Retrieved August 26, 2015, from http://www.parliament.uk/about/living-heritage/transformingsociety/livinglearning/school/overview/1870educationact/

DfE. (2009). *Deprivation and Education*. DfE. Retrieved from https://www.education.gov.uk/publications/standard/publicationDetail/Page1/DCSF-RTP-09-01

DfE. (2014, July). National curriculum - GOV.UK. Retrieved March 27, 2016, from https://www.gov.uk/government/collections/national-curriculum#curriculum-by-key-stages

DfES. (2003). *Building Bulletin 93 - Acoustic Design of Schools*. Stationery Office. Retrieved from http://www.education.gov.uk/schools/adminandfinance/schoolscapital/buildingsanddesign

DfES. (2004). *Building schools for the future: A new approach to capital investment*. Retrieved from http://webarchive.nationalarchives.gov.uk/20130401151715/https://www.education.gov.uk/p ublications/eOrderingDownload/DfES 0134 200MIG469.pdf

DfES. (2006). *Building Bulletin 101 - Ventilation of School Buildings*. Stationery Office. Retrieved from http://www.education.gov.uk/schools/adminandfinance/schoolscapital/buildingsanddesign

Dunn, R., Krimsky, J. S., Murray, J. B., & Quinn, P. J. (1985). Light up Their Lives: A Review of Research on the Effects of Lighting on Children's Achievement and Behavior. *The Reading Teacher*, *38*(9), 863–869. Retrieved from http://www.jstor.org/stable/20198961

Durán-Narucki, V. (2008). School building condition, school attendance, and academic achievement in New York City public schools: A mediation model. *Journal of Environmental Psychology*, *28*(3), 278–286. http://doi.org/10.1016/j.jenvp.2008.02.008

Education and Skills Committee. (2007). *Sustainable Schools: Are we buildings schools for the future?* House of Commons: The Stationery Office Limited. Retrieved from http://www.publications.parliament.uk/pa/cm200607/cmselect/cmeduski/140/140.pdf

Education Funding Agency. (2013). *Priority School Building Programme Services Output Specification*. Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/276993/psbp_sos_june_2013.pdf

Eisenhardt, K. M. (1989). Building Theories from Case Study Research. *The Academy of Management Review*, *14*(4), 532–550. http://doi.org/10.2307/258557

Fang, L., Wargocki, P., Witterseh, T., Clausen, G., & Fanger, P. O. (1999). Field study on the impact of temperature, humidity and ventilation on perceived air quality (pp. 107–112). Retrieved from http://forskningsbasen.deff.dk/Share.external?sp=Sbfd6390e-842f-473c-856d-bcc6180732e5&sp=Sdtu

Feilden Clegg Bradley Studios. (2009). *Places for Learning*. London: Feilden Clegg Bradley Studios. Retrieved from http://fcbstudios.com/about/books/view/places-for-learning

Field, A., & Miles, J. (2010). *Discovering Statistics Using SAS*. SAGE Publications. Retrieved from http://books.google.co.uk/books?id=tT1wiG8pWFQC

Finitzo-Hieber, T., & Tillman, T. W. (1978). Room acoustics effects on monosyllabic word discrimination ability for normal and hearing-impaired children. *Journal of Speech and Hearing Research*, *21*(3), 440–458. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/713515

Franklin, G. (2009). *Inner London Schools 1918-44: A Thematic Study*. English Heritage. Retrieved from http://services.english-heritage.org.uk/researchreportspdfs/043_2009web.pdf

Fuchs, T., & Wößmann, L. (2008). What accounts for international differences in student prformance? A re-examination using PISA data. In P. C. Dustmann, P. D. B. Fitzenberger, & P. S. Machin (Eds.) (pp. 209–240). Physica-Verlag HD. Retrieved from http://link.springer.com/chapter/10.1007/978-3-7908-2022-5_10

Gilliland, F. D., Berhane, K., Rappaport, E. B., Thomas, D. C., Avol, E., Gaudermann, W. J., … Islam, K. (2001). The effects of ambient air pollution on school absenteeism due to respiratory illnesses. *Epidemiology*, *12*(1), 43–54.

Gislason, N. (2009). Mapping school design: A qualitative study of the relations among facilities design, curriculum delivery, and school climate. *The Journal of Environmental Education*, *40*(4), 17–34. Retrieved from http://www.learningdomain.com/Architec.Learn.Envron.pdf

Gislason, N. (2010). Architectural design and the learning environment: A framework for school design research. *Learning Environments Research*, *13*(2), 127–145. http://doi.org/10.1007/s10984-010-9071-x

Global Action Plan. (2006). UK Schools Carbon Footprint Scoping Study. *Stockholm Environment Institute*, 1–76. Retrieved from http://www.se-ed.co.uk/sites/default/files/resources/GAP-Final-Report.pdf

Godoy-Shimizu, D., Armitage, P., Steemers, K., & Chenvidyakarn, T. (2011). Using Display Energy Certificates to quantify schools' energy consumption. *Building Research & Information*, *39*(6), 535–552. Retrieved from http://www.tandfonline.com/doi/abs/10.1080/09613218.2011.628457

Goe, L. (2007). *The Link between Teacher Quality and Student Outcomes: A Research Synthesis.*

National Comprehensive Center for Teacher Quality. Retrieved from http://eric.ed.gov/?id=ED521219

Goldstein, H., Browne, W., & Rasbash, J. (2002). Multilevel modelling of medical data. *Statistics in Medicine*, *21*(21), 3291–3315. http://doi.org/10.1002/sim.1264

Goldstein, H., & Spiegelhalter, D. J. (1996). League Tables and Their Limitations: Statistical Issues in Comparisons of Institutional Performance. *Journal of the Royal Statistical Society. Series A (Statistics in Society)*, *159*(3), 385–443. http://doi.org/10.2307/2983325

Goldstein, H., & Thomas, S. (1996). Using Examination Results as Indicators of School and College Performance. *Journal of the Royal Statistical Society. Series A (Statistics in Society)*, *159*(1), 149–163. http://doi.org/10.2307/2983475

Hanushek, E. A., & Woessmann, L. (2007). *The Role of Education Quality for Economic Growth*. Rochester, NY. Retrieved from http://papers.ssrn.com/abstract=960379

Hanushek, E. A., Woessmann, L., Jamison, E. A., & Jamison, D. T. (2008). Education and Economic Growth. *Education Next*, *8*(2). Retrieved from http://hanushek.stanford.edu/publications/education-and-economic-growth

Harwood, E. (2012). School Buildings and the architectural heritage of childhood. In *Children, Childhood and Cultural Heritage*.

Hatcher, R., & Jones, K. (2006). Researching Resistance: Campaigns Against Academies in England. *British Journal of Educational Studies*, *54*(3), 329–351. http://doi.org/10.1111/j.1467-8527.2006.00350.x

Hathaway, W. E. (1995). Effects of school lighting on physical development and school performance. *The Journal of Educational Research*, 228–242. Retrieved from http://www.nrc-cnrc.gc.ca/obj/irc/doc/pubs/ir/ir659/hathaway.pdf

Heschong, L., Wright, R., & Okura, S. (2002). Daylighting impacts on human performance in school. *Journal of the Illuminating …*, *4480*(October), 101–114. http://doi.org/10.1080/00994480.2002.10748396

Higgins, S., Hall, E., Wall, K., Woolner, P., & McCaughey, C. (2005). The Impact of School Environments: A literature review. *Design Council*, *10*, 47. Retrieved from http://128.240.233.197/cflat/news/DCReport.pdf

Hillier, B. (2007). *Space is the Machine* (Electronic). Space Syntax. Retrieved from http://discovery.ucl.ac.uk/3881/1/SITM.pdf

Hillier, B., & Grajewski, T. (1990). The application of space syntax to work environments inside buildings: second phase: towards a predictive model. *London, Unit for Architectural Studies, The Bartlett School of Architecture and Planning, University College London*.

Hillier, B., & Hanson, J. (1984). *The social logic of space* (Vol. 1). Cambridge university press Cambridge. Retrieved from http://www.academia.edu/download/30374693/Hiller___Hansen.pdf

Hillier, B., & Penn, A. (1991). Visible Colleges: Structure and Randomness in the Place of Discovery. *Science in Context*, *4*(01), 23–50. http://doi.org/10.1017/S0269889700000144

Hillier, B., Perm, A., Hanson, J., Grajewski, T., & Xu, J. (1993). Natural movement: or, configuration and attraction in urban pedestrian movement. *Environment and Planning B: Planning and Design*, *20*, 29–66. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.325.1421&rep=rep1&type=pdf

Hong, S.-M., Paterson, G., Mumovic, D., & Steadman, P. (2013). Improved benchmarking comparability for energy consumption in schools. *Building Research & Information*, *0*(0), 1–15. http://doi.org/10.1080/09613218.2013.814746

Hong, S.-M., Paterson, G., Mumovic, D., & Steadman, P. (2014). Improved benchmarking comparability for energy consumption in schools. *Building Research & Information*, *42*(1), 47–61. http://doi.org/10.1080/09613218.2013.814746

Hutcheson, G. D., & Sofroniou, N. (1999). *The multivariate social scientist: Introductory statistics using generalized linear models*. United Kingdom: Sage.

Jackson, D. A. (1993). Stopping Rules in Principal Components Analysis: A Comparison of Heuristical and Statistical Approaches. *Ecology*, *74*(8), 2204–2214.

http://doi.org/10.2307/1939574

James, S. (2011). *Review of education capital*. Retrieved from www.education.gov.uk/publications

Josephson, P.-E., & Hammarlund, Y. (1999). The causes and costs of defects in construction: A study of seven building projects. *Automation in Construction*, *8*(6), 681–687. http://doi.org/10.1016/S0926-5805(98)00114-9

Kearney, C. A. (2008). School absenteeism and school refusal behavior in youth: A contemporary review. *Clinical Psychology Review*, *28*(3), 451–471. http://doi.org/10.1016/j.cpr.2007.07.012

Kishimoto, T., & Taguchi, M. (2014). Spatial Configuration of Japanese Elementary Schools: Analyses by the Space Syntax and Evaluation by School Teachers. *Journal of Asian Architecture and Building Engineering*, *13*(2), 373–380. http://doi.org/10.3130/jaabe.13.373

Kjellberg, A., Landström, U., Tesarz, M., Söderberg, L., & Akerlund, E. (1996). The effects of nonphysical noise characteristics, ongoing task and noise sensitivity on annoyance and distraction due to noise at work. *Journal of Environmental Psychology*, *16*(2), 123–136. http://doi.org/06/jevp.1996.0010

Klarqvist, B. (1993). A space syntax glossary. *Nordisk Arkitekturforskning*, *2*(1), 11–12. Retrieved from https://fenix.tecnico.ulisboa.pt/downloadFile/3779573909551/glossarySS.pdf

Knez, I. (1995). Effects of indoor lighting on mood and cognition. *Journal of Environmental Psychology*, *15*(1), 39–51. http://doi.org/16/0272-4944(95)90013-6

Knez, I., & Hygge, S. (2002). Irrelevant speech and indoor lighting: effects on cognitive performance and self-reported affect. *Applied Cognitive Psychology*, *16*(6), 709–718. http://doi.org/10.1002/acp.829

Kraftl, P. (2012). Utopian Promise or Burdensome Responsibility? A Critical Analysis of the UK Government's Building Schools for the Future Policy. *Antipode*, *44*(3), 847–870. http://doi.org/10.1111/j.1467-8330.2011.00921.x

Küller, R., & Lindsten, C. (1992). Health and behavior of children in classrooms with and without windows. *Journal of Environmental Psychology*, *12*(4), 305–317.

http://doi.org/10.1016/S0272-4944(05)80079-9

Landmark. (n.d.). Non-Domestic Energy Performance Certificate Register. Retrieved November 23, 2012, from https://www.ndepcregister.com/

Leaman, A., & Bordass, B. (2001). Assessing building performance in use 4: the Probe occupant surveys and their implications. *Building Research & Information*, *29*(2), 129–143. http://doi.org/10.1080/09613210010008045

Leaman, A., & Bordass, B. (2007). Are users more tolerant of "green" buildings? *Building Research & Information*, *35*(6), 662. Retrieved from http://www.informaworld.com/10.1080/09613210701529518

Leather, P., Pyrgas, M., Beale, D., & Lawrence, C. (1998). Windows in the Workplace Sunlight, View, and Occupational Stress. *Environment and Behavior*, *30*(6), 739–762. http://doi.org/10.1177/001391659803000601

Leeuw, J. de, & Kreft, I. (2011). Software for Multilevel Analysis. *Department of Statistics, UCLA*. Retrieved from http://escholarship.org/uc/item/2xn1n7df

Libbey, H. P. (2004). Measuring Student Relationships to School: Attachment, Bonding, Connectedness, and Engagement. *Journal of School Health*, *74*(7), 274–283. http://doi.org/10.1111/j.1746-1561.2004.tb08284.x

Littlefair, P. J. (1988, November). Average daylight factor: a simple basis for daylight design. BRE. Retrieved from http://www.ihsti.com.libproxy.ucl.ac.uk/tempimg/28CA904-CIS888614800014535.pdf

Ludwig, J., & Miller, D. L. (2007). Does Head Start Improve Children's Life Chances? Evidence from a Regression Discontinuity Design. *Quarterly Journal of Economics*, *122*(1), 159–208. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=buh&AN=24400977&site=ehost-live

Mahony, P., & Hextall, I. (2009). "Building Schools for the Future"and its implications for becoming a teacher (pp. 28–30). Vienna. Retrieved from http://www.eeraecer.eu/fileadmin/user_upload/Publication_FULL_TEXTS/ECER2009_545_Mahony_01.doc

Mahony, P., & Hextall, I. (2013). “Building Schools for the Future”: “transformation” for social justice or expensive blunder? *British Educational Research Journal*, *39*(5), 853–871. http://doi.org/10.1002/berj.3001

Mahony, P., Hextall, I., & Richardson, M. (2011a). “Building Schools for the Future”: reflections on a new social architecture. *Journal of Education Policy*, *26*(3), 341–360. http://doi.org/10.1080/02680939.2010.513741

Mahony, P., Hextall, I., & Richardson, M. (2011b). “Building Schools for the Future”: reflections on a new social architecture. *Journal of Education Policy*, *26*(3), 341–360. http://doi.org/10.1080/02680939.2010.513741

Malcolm, H., Thorpe, G., & Lowden, K. (1996). *Understanding truancy: Links between attendance, truancy and performance*. Edinburgh: Scottish Council for Research in Education. Retrieved from http://dspace.gla.ac.uk:8080/handle/1905/251

Martin, S. H. (2002). The classroom environment and its effects on the practice of teachers. *Journal of Environmental Psychology*, *22*(1–2), 139–156. http://doi.org/10.1006/jevp.2001.0239

Mattsson, M., & Hygge, S. (2005). *Effect of particulate air cleaning on perceived health and cognitive performance in school children during pollen season*. (X. Yang, B. Zhao, & R. Zhao, Eds.). Beijing: Tsinghua University Press.

McEvoy, A., & Welker, R. (2000). Antisocial Behavior, Academic Failure, and School Climate: A Critical Review. *Journal of Emotional and Behavioral Disorders*, *8*(3), 130–140. http://doi.org/10.1177/106342660000800301

Mendell, M. J., & Heath, G. A. (2005). Do indoor pollutants and thermal conditions in schools influence student performance? A critical review of the literature. *Indoor Air*, *15*(1), 27–52. http://doi.org/10.1111/j.1600-0668.2004.00320.x

Mitchell, W. J., Steadman, J. P., & Liggett, R. S. (1976). Synthesis and optimization of small rectangular floor plans. *Environment and Planning B: Planning and Design*, *3*(1), 37 – 70.

http://doi.org/10.1068/b030037

Moezzi, M., & Goins, J. (2011). Text mining for occupant perspectives on the physical workplace. *Building Research & Information*, *39*(2), 169. Retrieved from http://www.informaworld.com/10.1080/09613218.2011.556008

Moore, G., Croxford, B., Adams, M., Refaee, M., Cox, T., & Sharples, S. (2008). The photo-survey research method: capturing life in the city. *Visual Studies*, *23*(1), 50–62. http://doi.org/10.1080/14725860801908536

Moore, G. T., & Lackney, J. A. (1993). School Design: Crisis, Educational Performance and Design Applications. *Children's Environments*, *10*(2), 99–112. Retrieved from http://www.jstor.org/stable/41514884

Mosher, R., & MacGowan, B. (1985). Assessing Student Engagement in Secondary Schools: Alternative Conceptions, Strategies of Assessing, and Instruments. Retrieved from http://eric.ed.gov/?id=ED272812

Mott, M. S., Robinson, D. H., Walden, A., Burnette, J., & Rutherford, A. S. (2012). Illuminating the Effects of Dynamic Lighting on Student Learning. *SAGE Open*, *2*(2), 2158244012445585. http://doi.org/10.1177/2158244012445585

Mumovic, D., Palmer, J., Davies, M., Orme, M., Ridley, I., Oreszczyn, T., … Way, P. (2009). Winter indoor air quality, thermal comfort and acoustic performance of newly built secondary schools in England. *Building and Environment*, *44*(7), 1466–1477. http://doi.org/10.1016/j.buildenv.2008.06.014

Myhrvold, A. N., Olsen, E., & Lauridsen, O. (1996). Indoor environment in schools–pupils health and performance in regard to CO2 concentrations (pp. 369–371). Retrieved from http://www.aretas.ca/sites/default/files/imce_images/Indoor Environment in Schools %E2%80%93 Pupils Health %26 Performance in Regard to CO2 Concentrations.pdf

NUT. (n.d.). Academies | National Union of Teachers - NUT. Retrieved December 3, 2014, from https://www.teachers.org.uk/academies

OECD. (n.d.-a). PISA - OECD. Retrieved August 30, 2015, from http://www.oecd.org/pisa/

OECD. (n.d.-b). United Kingdom - OECD. Retrieved September 13, 2015, from http://www.oecd.org/unitedkingdom/

Ofcom. (n.d.). Ofcom | Facts & figures. Retrieved December 9, 2014, from http://media.ofcom.org.uk/facts/

Otto, D. A., Hudnell, H. K., House, D. E., Mølhave, L., & Counts, W. (1992). Exposure of Humans to a Volatile Organic Mixture. I. Behavioral Assessment. *Archives of Environmental Health: An International Journal*, *47*(1), 23–30. http://doi.org/10.1080/00039896.1992.9935940

Owens, R., & Valesky, T. (2007). *Organizational Behavior in Education: Adaptive Leadership and School Reform* (9th ed.). Toronto: Pearson Higher Education, Inc.

Pasalar, C. (2004). *The Effects of Spatial Layouts on Students' Interactions in Middle Schools: Multiple Case Analysis*. Retrieved from http://www.lib.ncsu.edu/resolver/1840.16/5083

Pasalar, Ç. (2007). Spaces for Learning Through Better Social Interaction. In E. Knapp, K. Noschis, & Ç. Pasalar (Eds.) (p. 51). Lausanne: Comportements. Retrieved from http://sdpl.coe.uga.edu/HTML/SchoolBuildingDesign%26LP.pdf#page=50

Penn, A. (2001). Space Syntax and Spatial Cognition: Or, why the axial line? Atlanta. Retrieved from http://eprints.ucl.ac.uk/3419/1/3419.pdf

Peponis, J., Conroy-Dalton, R., Wineman, J., & Dalton, N. (2004). Measuring the effects of layout upon visitors' spatial behaviors in open plan exhibition settings. *Environment and Planning B: Planning and Design*, *31*, 453–473. Retrieved from http://discovery.ucl.ac.uk/1096/1/MELuVSB.pdf.pdf

Peponis, J., Wineman, J., Bafna, S., Rashid, M., & Kim, S. H. (1998). On the generation of linear representations of spatial configuration. *Environment and Planning B: Planning and Design*, *25*(4), 559 – 576. http://doi.org/10.1068/b250559

Peretti, C., & Schiavon, S. (2011). Indoor environmental quality surveys. A brief literature review. *Center for the Built Environment*. Retrieved from http://escholarship.org/uc/item/0wb1v0ss

Picard, M., & Bradley, J. S. (2001). Revisiting Speech Interference in Classrooms. *International*

*Journal of Audiology*, *40*(5), 221–224. Retrieved from http://informahealthcare.com.libproxy.ucl.ac.uk/doi/abs/10.3109/00206090109073117

Pilotto, L. S., Douglas, R. M., Attewell, R. G., & Wilson, S. R. (1997). Respiratory effects associated with indoor nitrogen dioxide exposure in children. *International Journal of Epidemiology*, *26*(4), 788–796. http://doi.org/10.1093/ije/26.4.788

Powell, K. (2010). Making Sense of Place: Mapping as a Multisensory Research Method. *Qualitative Inquiry*, *16*(7), 539–555. http://doi.org/10.1177/1077800410372600

Raffe, D. (2004). How Distinctive is Scottish Education? Five Perspectives on Distinctiveness. *Scottish Affairs*, *49 (First* (1), 50–72. http://doi.org/10.3366/scot.2004.0055

Ransom, M. R., & Pope III, C. A. (1992). Elementary school absences and PM10 pollution in Utah Valley. *Environmental Research*, *58*(1–2), 204–219. http://doi.org/10.1016/S0013-9351(05)80216-6

Rasbash, J., Charlton, C., Browne, W. J., Healy, M., & Cameron, B. (2014). MLwiN Version 2.30.

Rasbash, J., Steele, F., Browne, W. J., & Goldstein, H. (2014). *A User's Guide to MLwiN, v2.31*. United Kingdom: Centre for Multilevel Modelling, University of Bristol.

Rintala, K., & Griggs, R. (2009). *PFI in school building - does it influence educational outcomes?* (RRD-129963). Retrieved from http://www.kpmg.eu/docs/20100120_PFI-in-school-building.pdf

Robson, E. R. (1972). *School architecture / E.R. Robson* ([1st ed. r). Leicester: Leicester University Press.

Roethlisberger, W. J., & Dickson, F. J. (2013). Management and the Worker. *Royal Economic Society Journal*, *51*(202), 306–308. http://doi.org/10.2307/2226267

Rowe, K. (2003). The importance of teacher quality as a key determinant of students' experiences and outcomes of schooling. *2003-Building Teacher Quality: What Does the Research Tell Us?*, 3. Retrieved from http://research.acer.edu.au/cgi/viewcontent.cgi?article=1001&context=research_conference_

2003

Ryan, A. M., & Patrick, H. (2001). The Classroom Social Environment and Changes in Adolescents' Motivation and Engagement During Middle School. *American Educational Research Journal*, *38*(2), 437–460. http://doi.org/10.3102/00028312038002437

Sailer, K. (2007). MOVEMENT IN WORKPLACE ENVIRONMENTS: configurational or programmed? 068. Retrieved from http://www.spacesyntaxistanbul.itu.edu.tr/papers\longpapers\068 - Sail

Sailer, K. (2010). *The space-organisation relationship : on the shape of the relationship between spatial configuration and collective organisational behaviours / Kerstin Sailer*. Retrieved from http://www.dart-europe.eu/full.php?id=303921

Sammons, P., Gu, Q., Day, C., & Ko, J. (2011). Exploring the impact of school leadership on pupil outcomes: Results from a study of academically improved and effective schools in England. *International Journal of Educational Management*, *25*(1), 83–101. http://doi.org/10.1108/09513541111100134

SAS Institute Inc. (2013). The FACTOR Procedure. North Carolina: SAS Institute Inc. Retrieved from http://support.sas.com/documentation/onlinedoc/stat/131/factor.pdf

Schoeneberger, J. A. (2011). RDPLOT: A SAS Macro for Generating Regression Discontinuity Plots. Alexandria, VA: Institute for Advanced Analytics. Retrieved from http://analytics.ncsu.edu/?page_id=3375

Seager, A. (2015, March). *Oral evidence: Priority Schools Building Programme, HC 1090*. House of Commons, London: House of Commons: The Stationery Office Limited. Retrieved from http://data.parliament.uk/writtenevidence/committeeevidence.svc/evidencedocument/education-committee/priority-schools-building-programme/oral/18617.pdf

Seashore, K., Leithwood, K., Wahlstrom, K., & Anderson, S. (2010). *Investigating the Links to Improved Student Learning: Final Report of Research Findings*. Retrieved from http://conservancy.umn.edu/handle/11299/140885

Shaughnessy, R. J., Haverinen-Shaughnessy, U., Nevalainen, A., & Moschandreas, D. (2006). A preliminary study on the association between ventilation rates in classrooms and student performance. *Indoor Air*, *16*(6), 465–468. http://doi.org/10.1111/j.1600-0668.2006.00440.x

Shendell, D. G., Prill, R., Fisk, W. J., Apte, M. G., Blake, D., & Faulkner, D. (2004). Associations between classroom CO2 concentrations and student attendance in Washington and Idaho. *Indoor Air*, *14*(5), 333–341. http://doi.org/10.1111/j.1600-0668.2004.00251.x

Shield, B., Asker, R., & Tachmatzidis, I. (2002). *The effects of noise on the attainments and cognitive development of primary school children.*

Shield, B., & Dockrell, J. (2003). The Effects of Noise on Children at School: A Review. *Building Acoustics*, *10*(2), 97–116. http://doi.org/10.1260/135101003768965960

Sime, J. D. (1985). Designing for people or ball-bearings? *Design Studies*, *6*(3), 163–168. http://doi.org/10.1016/0142-694X(85)90007-9

Sime, J. D. (1986). Creating Places or Desgining Spaces? *Journal of Environmental Psychology*, *6*, 49–63.

Singer, J. D. (1998). Using SAS PROC MIXED to Fit Multilevel Models, Hierarchical Models, and Individual Growth Models. *Journal of Educational and Behavioral Statistics*, *23*(4), 323–355. http://doi.org/10.3102/10769986023004323

Stansfeld, S. A., & Matheson, M. P. (2003). Noise pollution: non-auditory effects on health. *British Medical Bulletin*, *68*(1), 243 –257. http://doi.org/10.1093/bmb/ldg033

Steadman, P. (2008). *The Evolution of Designs: Biological Analogy in Architecture and the Applied Arts*. Routledge. Retrieved from https://books.google.co.uk/books?id=szfFn-VE0QMC

Steadman, P. (2014). *Building types and built forms / Philip Steadman.* Kibworth Beauchamp, Leicestershire: Matador.

Stern, P. N. (1980). Grounded Theory Methodology: Its Uses and Processes. *Image*, *12*(1), 20–23. http://doi.org/10.1111/j.1547-5069.1980.tb01455.x

Stevens, J. P. (2012). *Applied Multivariate Statistics for the Social Sciences, Fifth Edition*. Routledge. Retrieved from http://books.google.co.uk/books?id=oIeDhzDebKwC

Tagiuri, R., Litwin, G. H., & Barnes, L. B. (1968). *Organizational climate: Explorations of a concept*. Division of Research, Graduate School of Business Administration, Harvard University Boston, MA. Retrieved from http://library.wur.nl/WebQuery/clc/1625477

The Guardian. (2010, July). Full list of the scrapped school building projects | Education | theguardian.com. Retrieved September 13, 2015, from http://www.theguardian.com/education/interactive/2010/jul/05/building-schools-for-the-future-michael-gove

Thistlethwaite, D. L., & Campbell, D. T. (1960). Regression-discontinuity analysis: An alternative to the ex post facto experiment. *Journal of Educational Psychology*, *51*(6), 309–317. http://doi.org/10.1037/h0044319

TIMSS and PIRLS. (n.d.). TIMSS and PIRLS International Study Center. Retrieved August 30, 2015, from http://timssandpirls.bc.edu/

Turner, A. (2003). Analysing the visual dynamics of spatial morphology. *Environment and Planning B*, *30*(5), 657–676. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.109.3290&rep=rep1&type=pdf

Turner, A. (2004). Depthmap 4: a researcher's handbook. Retrieved from http://eprints.ucl.ac.uk/2651

Turner, A., Doxa, M., O'Sullivan, D., & Penn, A. (2001). From isovists to visibility graphs: a methodology for the analysis of architectural space. *Environment and Planning B: Planning and Design*, *28*(1), 103–121. http://doi.org/10.1068/b2684

Turner, A., Doxa, M., O'sullivan, D., & Penn, A. (2001). From isovists to visibility graphs: a methodology for the analysis of architectural space. *ENVIRON PLANN B*, *28*(1), 103–121. Retrieved from http://eprints.ucl.ac.uk/160/1/turner-doxa-osullivan-penn-2001.pdf

Turner, A., & Penn, A. (1999). Making Isovists Syntactic: Isovist Integration Analysis (pp. 103–121). Universidad de Brasilia, Brazil. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.126.685

Turner, A., Penn, A., & Hillier, B. (2005). An algorithmic definition of the axial map. *Environment* *and Planning B: Planning and Design*, *32*(3), 425–444.

Tzortzi, K. (2004). Building and exhibition layout: Sainsbury Wing compared with Castelvecchio. *Arq: Architectural Research Quarterly*, *8*(02), 128–140. http://doi.org/10.1017/S1359135504000168

Van Gemert, L. J. (2006). *Odour thresholds: compilations of odour thresholds values in air, water and other media*. Utrecht, Netherlands: Oliemans Punter and Partners.

Varoudis, T. (2012). DepthmapX Multi-Platform Spatial Network Analysis Software. Retrieved from http://varoudis.github.io/depthmapX/

Varoudis, T., & Psarra, S. (2014). Beyond two dimensions: Architecture through three-dimensional visibility graph analysis. *Journal of Space Syntax*, *5*(1), 91–108.

Vesma, V. (n.d.). Energy management A to Z. Retrieved November 26, 2012, from http://www.vesma.com/

W3C. (2011, November). CSS/Selectors - Web Education Community Group. Retrieved December 9, 2014, from http://www.w3.org/community/webed/wiki/CSS/Selectors

Wargocki, P., & Wyon, D. (2007). The Effects of Moderately Raised Classroom Temperatures and Classroom Ventilation Rate on the Performance of Schoolwork by Children (RP-1257). *HVAC&R Research*, *13*(2), 193–220. http://doi.org/10.1080/10789669.2007.10390951

Wargocki, P., & Wyon, D. P. (2013). Providing better thermal and air quality conditions in school classrooms would be cost-effective. *Building and Environment*, *59*, 581–589. http://doi.org/10.1016/j.buildenv.2012.10.007

Webb, D. (2007). Modes of hoping. *History of the Human Sciences*, *20*(3), 65–83. http://doi.org/10.1177/0952695107079335

Wenglinsky, H. (2002). The Link Between Teacher Classroom Practices and Student Academic Performance. *Education Policy Analysis Archives*, *10*, 12. Retrieved from http://epaa.asu.edu/ojs/article/view/291

Willis, G. B. (2004). *Cognitive interviewing: A tool for improving questionnaire design*. Sage

Publications. Retrieved from http://www.hkr.se/pagefiles/35002/gordonwillis.pdf

Winterbottom, M., & Wilkins, A. (2009). Lighting and discomfort in the classroom. *Journal of Environmental Psychology*, *29*(1), 63–75.

Wollin, D. D., & Montague, M. (1981). College Classroom Environment: Effects of Sterility Versus Amiability on Student and Teacher Performance. *Environment and Planning B*, *13*(6), 707–716. Retrieved from http://pao.chadwyck.co.uk/PDF/1322149637249.pdf

Wong, N. H., & Khoo, S. S. (2003). Thermal comfort in classrooms in the tropics. *Energy and Buildings*, *35*(4), 337–351. http://doi.org/10.1016/S0378-7788(02)00109-3

Woolner, P., Hall, E., Higgins, S., McCaughey, C., & Wall, K. (2007). A Sound Foundation? What We Know about the Impact of Environments on Learning and the Implications for Building Schools for the Future. *Oxford Review of Education*, *33*(1), 47–70. Retrieved from http://www.jstor.org/stable/4618696

Woolner, P., Hall, E., Wall, K., & Dennison, D. (2007). Getting together to improve the school environment: user consultation, participatory design and student voice. *Improving Schools*, *10*(3), 233–248. http://doi.org/10.1177/1365480207077846

World Health Organization. (2010). *WHO guidelines for indoor air quality: selected pollutants*. Copenhagen: WHO Regional Office for Europe. Retrieved from http://www.euro.who.int/__data/assets/pdf_file/0009/128169/e94535.pdf

Wößmann, L. (2003). Schooling Resources, Educational Institutions and Student Performance: the International Evidence. *Oxford Bulletin of Economics and Statistics*, *65*(2), 117–170. http://doi.org/10.1111/1468-0084.00045

Wu, W., & Ng, E. (2003). A review of the development of daylighting in schools. *Lighting Research and Technology*, *35*(2), 111 –124. http://doi.org/10.1191/1477153503li072oa

Wurtman, R. J. (1975). The effects of light on the human body. *Scientific American*, *233*(1), 68–77. Retrieved from http://web.mit.edu/dick/www/pdf/286.pdf

Yildirim, K., Akalin-Baskaya, A., & Celebi, M. (2007). The effects of window proximity, partition height, and gender on perceptions of open-plan offices. *Journal of Environmental Psychology*, *27*(2), 154–165. http://doi.org/10.1016/j.jenvp.2007.01.004

Zagreus, L., Huizenga, C., Arens, E., & Lehrer, D. (2004). Listening to the occupants: a web-based indoor environmental quality survey. *Center for the Built Environment*. Retrieved from http://escholarship.org/uc/item/8cf6c6dr

Zeedyk, M. S., Gallacher, J., Henderson, M., Hope, G., Husband, B., & Lindsay, K. (2003). Negotiating the Transition from Primary to Secondary School Perceptions of Pupils, Parents and Teachers. *School Psychology International*, *24*(1), 67–79. http://doi.org/10.1177/0143034303024001010

Zhou, X.-H., Perkins, A. J., & Hui, S. L. (1999). Comparisons of Software Packages for Generalized Linear Multilevel Models. *The American Statistician*, *53*(3), 282–290. http://doi.org/10.2307/2686112

Zullig, K. J., Koopman, T. M., Patton, J. M., & Ubbes, V. A. (2010). School Climate: Historical Review, Instrument Development, and School Assessment. *Journal of Psychoeducational Assessment*, *28*(2), 139–152. http://doi.org/10.1177/0734282909344205

# Appendix A. Variable included in unified school database

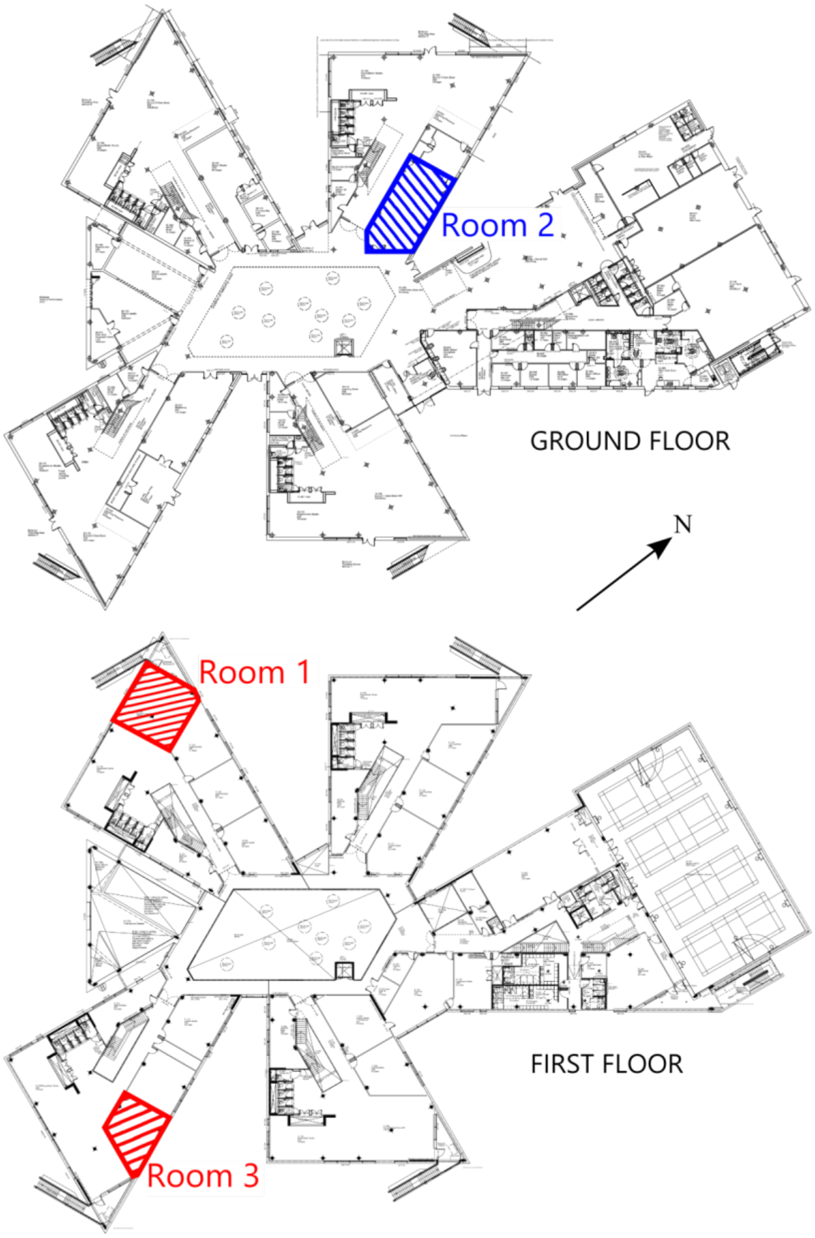
| Num | Variable | Type | Label |
|---|---|---|---|
| 1 | AcadYear | Char | Academic Year |
| 2 | B01 | Num | B01 Committed revenue balances |
| 3 | B02 | Num | B02 Uncommitted revenue balances |
| 4 | B03 | Num | B03 Devolved formula capital balance |
| 5 | B04 | Num | B04 Other Standards Fund capital balances |
| 6 | B05 | Num | B05 Other capital balances |
| 7 | BREEAMVGood | Char | Has the project achieved BREEAM "VGood" or better? |
| 8 | CE01 | Num | CE01 Acquisition of land and existing buildings |
| 9 | CE02 | Num | CE02 New construction, conversion, and renovation |
| 10 | CE03 | Num | CE03 Vehicles, plant, equipment and machinery |
| 11 | CE04 | Num | CE04 Information and communication technology (ICT) |
| 12 | CI01 | Num | CI01 Capital income |
| 13 | CI02 | Num | CI02 Loans removed 2006/07 |
| 14 | CI03 | Num | CI03 Voluntary or Private income |
| 15 | CI04 | Num | CI04 Direct revenue financing (revenue contributions to capital) |
| 16 | CO2Emission | Num | CO2 emissions per sqm per annum |
| 17 | CalcEngine | Char | DEC Calculation Engine |
| 18 | CalcEngineName | Char | Calculation Tool Version |
| 19 | CalcEngineVersion | Char | Calculation Tool Name |
| 20 | CarbonCalc | Char | Compliance with requirement to reduce carbon emissions by 60%, a |
| 21 | CateringType | Char | Catering kitchens (indicate if for reheating food, cooking from |
| 22 | CompletionDate | Num | Actual or planned date of completion (Month/Year) |
| 23 | ConAcadYear | Num | Academic Year of Construction |
| 24 | DECEndDate | Num | DEC End Date |
| 25 | Deprivation | Num | Deprivation Indicator |
| 26 | DesktopPC | Num | DesktopPC Numbers |
| 27 | DiffFSM | Num | Free School Meal percentage difference from national average |
| 28 | DiffLev1 | Num | Level 1 Difference from Average |
| 29 | DiffLev2 | Num | Level 2 Difference from Average |
| 30 | DiffSEN | Num | SEN percentage difference from national average |
| 31 | DiffTotabs | Num | Total Absence difference from average |
| 32 | DiffUnauth | Num | Unauthorised absence difference from Average |
| 33 | E01 | Num | E01 Teaching staff |
| 34 | E02 | Num | E02 Supply teaching staff |
| 35 | E03 | Num | E03 Education support staff |
| 36 | E04 | Num | E04 Premises staff |
| 37 | E05 | Num | E05 Administrative & clerical staff |
| 38 | E06 | Num | E06 Catering staff |

| Num | Variable | Type | Label |
|---|---|---|---|
| 39 | E07 | Num | E07 Cost of other staff |
| 40 | E08 | Num | E08 Indirect employee expenses |
| 41 | E09 | Num | E09 Development and training |
| 42 | E10 | Num | E10 Supply teacher insurance |
| 43 | E11 | Num | E11 Staff related insurance |
| 44 | E12 | Num | E12 Building maintenance and improvement |
| 45 | E13 | Num | E13 Grounds maintenance and improvement |
| 46 | E14 | Num | E14 Cleaning and caretaking |
| 47 | E15 | Num | E15 Water & sewerage |
| 48 | E16 | Num | E16 Energy |
| 49 | E17 | Num | E17 Rates |
| 50 | E18 | Num | E18 Other occupation costs |
| 51 | E19 | Num | E19 Learning resources (not ICT equipment) |
| 52 | E20 | Num | E20 ICT learning resources |
| 53 | E21 | Num | E21 Exam Fees |
| 54 | E22 | Num | E22 Administrative supply |
| 55 | E23 | Num | E23 Other insurance premiums |
| 56 | E24 | Num | E24 Special facilities |
| 57 | E25 | Num | E25 Catering supplies |
| 58 | E26 | Num | E26 Agency supply teaching staff |
| 59 | E27 | Num | E27 Bought in professional services curriculum |
| 60 | E28 | Num | E28 Bought in professional services other |
| 61 | E29 | Num | E29 Loan Interest |
| 62 | E30 | Num | E30 Direct Revenue Financing (Revenue contributions to capital) |
| 63 | E31 | Num | E31 Community focussed extended school staff |
| 64 | E32 | Num | E32 Community focussed extended school costs |
| 65 | E04Pup | Num | Premises Staff per pupil (/pupil) |
| 66 | E12Pup | Num | Building maintenance and improvement per pupil (/pupil) |
| 67 | E13Pup | Num | Ground maintenance and improvement per pupil (/pupil) |
| 68 | E14Pup | Num | Cleaning and caretaking per pupil (/pupil) |
| 69 | E15Pup | Num | Water and sewerage per pupil (/pupil) |
| 70 | E16Pup | Num | Energy per pupil (/pupil) |
| 71 | EPCFA | Num | Floor area from EPC |
| 72 | EPCRating | Num | EPC Rating |
| 73 | EPC_Date | Num | Lodgement Date of EPC |
| 74 | ElecCons | Num | Elect cons |
| 75 | ElecCost | Num | Elect cost |
| 76 | ElecM2 | Num | Electricity kWh/m2 |
| 77 | EnergyCost | Num | Energy Cost from PFS or CFR Data |
| 78 | Engine_Version | Char | Engine Version |
| 79 | Estab | Num | estab number |
| 80 | EstabType | Char | TypeOfEstablishment (name) |
| 81 | FA | Num | Internal floor area |

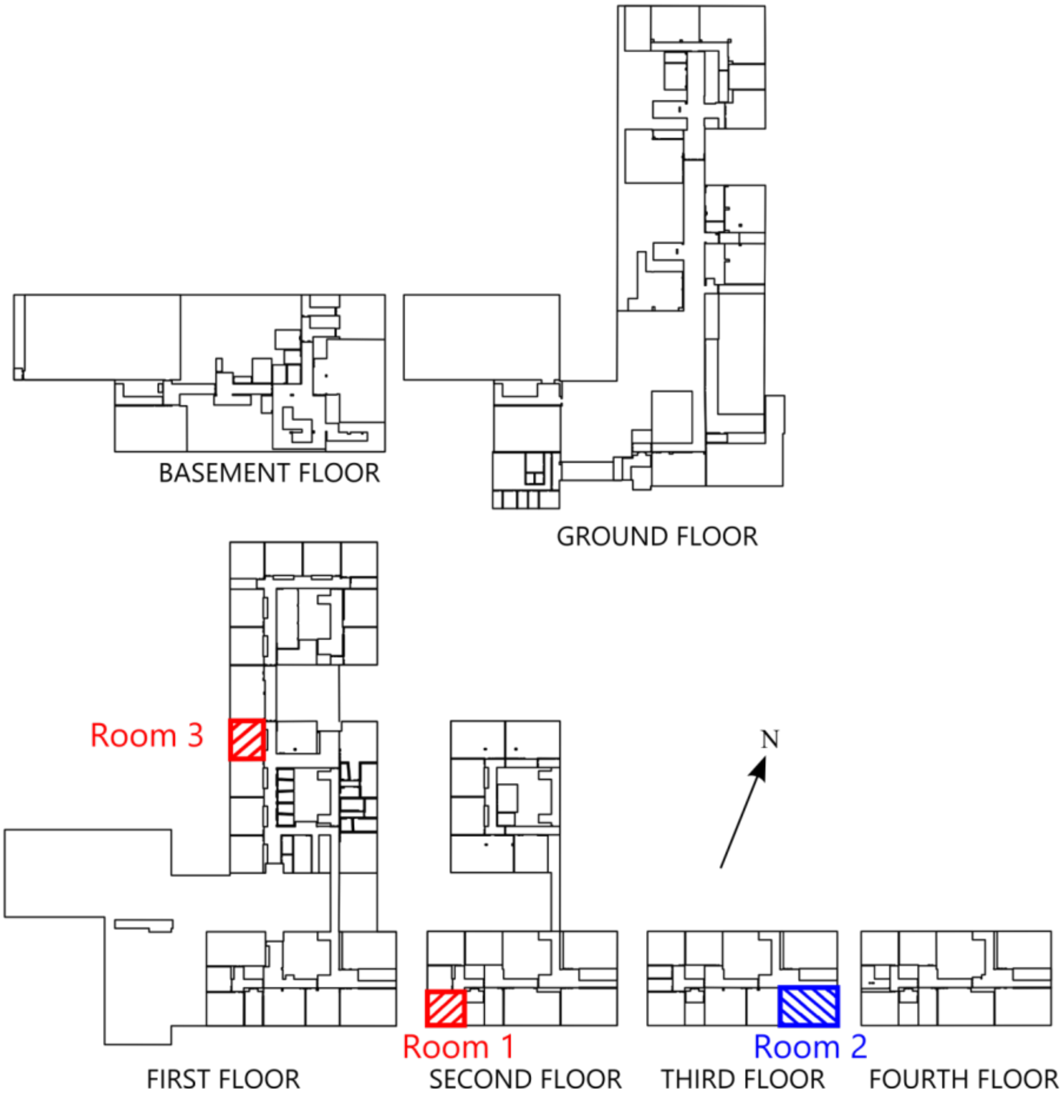
| Num | Variable | Type | Label |
|---|---|---|---|
| 82 | FTEOther | Num | Full time equivalent total other teachers |
| 83 | FTEPupils | Num | Full time equivalent pupils |
| 84 | FTETeach | Num | Full time equivalent teachers and non-teachers |
| 85 | GasCons | Num | Gas Consumption |
| 86 | GasCost | Num | Gas Cost |
| 87 | HVAC | Char | HVAC System |
| 88 | HtgM2 | Num | Heating kWh/m2 |
| 89 | I01 | Num | I01 Funds delegated by the LA |
| 90 | I02 | Num | I02 Funding for 6th form students |
| 91 | I03 | Num | I03 SEN funding |
| 92 | I04 | Num | I04 Funding for minority ethnic pupils |
| 93 | I05 | Num | I05 Standards Fund |
| 94 | I06 | Num | I06 Other government grants |
| 95 | I07 | Num | I07 Other grants and payments |
| 96 | I08 | Num | I08 Income from facilities and services |
| 97 | I09 | Num | I09 Income from catering |
| 98 | I10 | Num | I10 Receipts from supply teacher insurance claims |
| 99 | I11 | Num | I11 Receipts from other insurance claims |
| 100 | I12 | Num | I12 Income from contributions to visits etc. |
| 101 | I13 | Num | I13 Donations and/or private funds |
| 102 | I14 | Num | I14 SSG pupil focussed |
| 103 | I15 | Num | I15 Pupil focussed extended school funding and/or grants |
| 104 | I16 | Num | I16 Community focussed extended school funding and/or grants |
| 105 | I17 | Num | I17 Community focussed extended school facilities income |
| 106 | ICTInvest | Char | Significant ICT investment (indicate if yes) |
| 107 | IntEnv | Char | IntEnv |
| 108 | LA | Num | Local Authority |
| 109 | LAEstab | Num | Local Education Authority/Estab Number |
| 110 | LEA | Num | Local Education Authority |
| 111 | LPGCons | Num | LPG Consumption |
| 112 | LPGCost | Num | LPG Cost |
| 113 | Lev1 | Num | % Achieved 5+ A*-G GCSEs |
| 114 | Lev2 | Num | % Achieved 5+ A*-C GCSEs |
| 115 | Lev1_Mean | Num | % Achieved 5+ A*-G GCSEs |
| 116 | Lev2_Mean | Num | % Achieved 5+ A*-C GCSEs |
| 117 | MHF | Char | Main Heating Fuel |
| 118 | NOS_Level | Num | DEC Complexity Level |
| 119 | NewRebuilt | Char | New or rebuilt school |
| 120 | NoBlocks | Num | Number of Blocks |
| 121 | NoSites | Num | Number of Sites |
| 122 | NumElFSM | Num | Number of pupils known to be eligible for free school meals |
| 123 | NumTakeFSM | Num | Number of pupils taking free school meals |

| Num | Variable | Type | Label |
|---|---|---|---|
| 124 | OilCons | Num | Oil Consumption |
| 125 | OilCost | Num | Oil Cost |
| 126 | OverallCO2 | Num | Overall CO2 Emissions (kgCO2/sqm/annum) |
| 127 | OverallEPC | Num | EPC for Building |
| 128 | PCtSenWO | Num | % of pupils with special needs with statements |
| 129 | PCtSenWO_Mean | Num | % of pupils with special needs with statements |
| 130 | PFI | Char | PFI (name) |
| 131 | PctElFSM | Num | % of pupils known to be eligible for free school meals |
| 132 | PctElFSM_Mean | Num | % of pupils known to be eligible for free school meals |
| 133 | PctSENWith | Num | % of pupils with special needs without statements |
| 134 | PctTakeFSM | Num | % of pupils taking free school meals |
| 135 | Phase | Char | PhaseOfEducation (name) |
| 136 | Postcode | Char | Postcode |
| 137 | PupTeachRatio | Num | pupil:teacher ratio |
| 138 | RegEngine | Char | Calculation Engine Name |
| 139 | SchoolCap | Num | School Capacity |
| 140 | SchoolName | Char | School Name |
| 141 | SigRefurb | Char | School planned to be significantly refurbished (>80% of school or more) |
| 142 | SoildCost | Num | Solid Fuel Cost |
| 143 | SolidCost | Num | Solid Fuel Consumption |
| 144 | TSENA | Num | Total SEN pupils without statements |
| 145 | TSENSAP | Num | Total SEN pupils with statements |
| 146 | TUFA | Num | Floor area |
| 147 | TotAbs | Num | % of half days missed |
| 148 | TotAbs_Mean | Num | % of half days missed |
| 149 | TotElec | Num | Total Electricity kWh/annum |
| 150 | TotHtg | Num | Total Heating kWh/annum |
| 151 | TotalCO2 | Num | Estimated Building CO2 emissions (kgCO2/annum) |
| 152 | Unauth | Num | % of half days missed without authorisation |
| 153 | Unauth_Mean | Num | % of half days missed without authorisation |
| 154 | UrbanRural | Num | Urban_Rural |
| 155 | WaterConsumption | Num | WaterConsumption |
| 156 | WaterCost | Num | Water Cost |
| 157 | Year | Num | End of Academic Year |
| 158 | YearNewBuild | Num | Years before/after new school building |
| 159 | minimis | Num | Minimis for finance |
| 160 | urn | Num | Unique Reference Number (URN) |

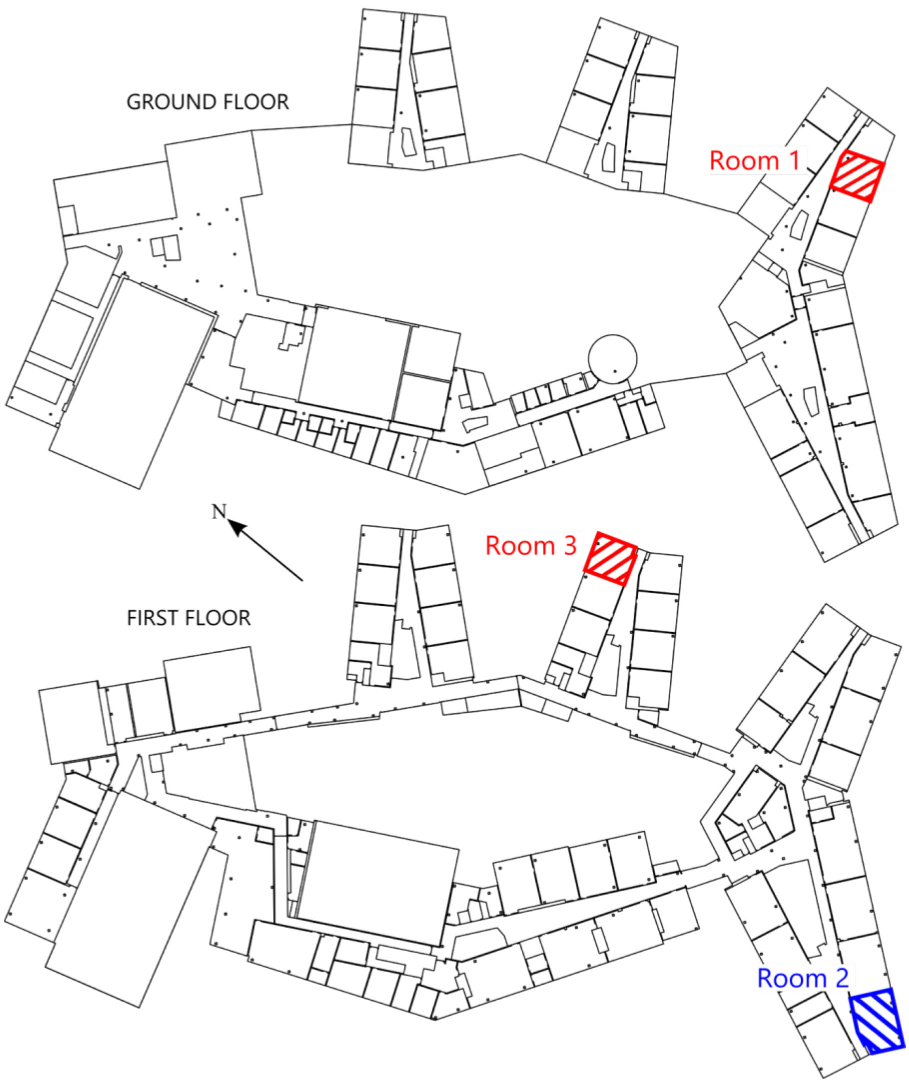
## Appendix B. School Layout Plans



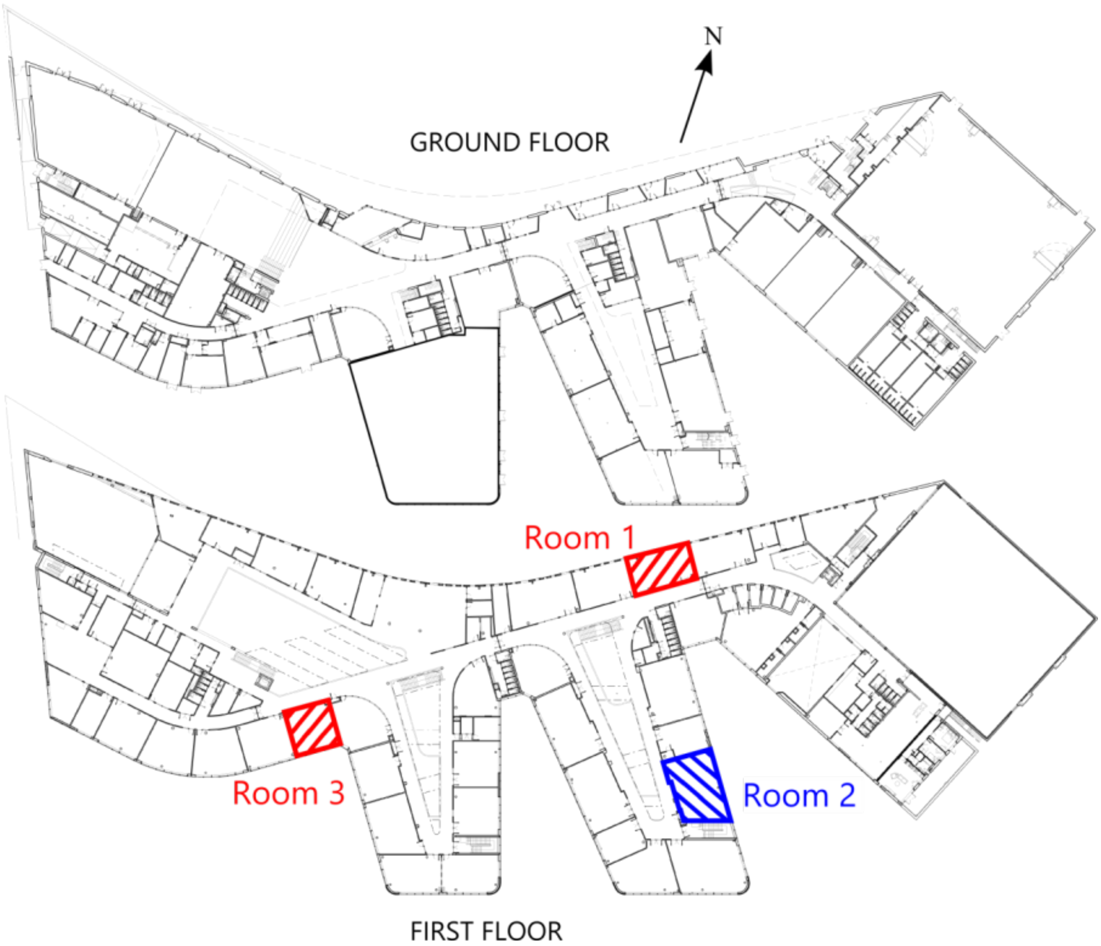

Plan of School A showing the locations of the monitored classrooms. (Note: science classroom highlighted in blue)




Plan of School B showing the location of the monitored classrooms. (Note: science classroom highlighted in blue)




Plan of School C showing the locations of the monitored classrooms. (Note: science classroom highlighted in blue)




Plan showing the locations of the monitored classrooms. (Note: science classroom highlighted in blue)

# Appendix C. Student Questionnaire

Note question codes are shown in red boxes, but were not included in the printed versions.

UCL

## School Assessment Questionnaire - Students

### Thank you for taking the time to complete this questionnaire.

Using this questionnaire, we hope to find out how your building is performing and how we can make this building, and future buildings, perform better.
Please answer as many questions as possible. There are three sections: about yourself, about how you feel about the school, and about you feel about the building. There is space provided at the end for any comments for you to enter any thoughts or justification for your responses. All responses will be anonymous, with only overall results shared. There are **three pages** in total.
If you have any queries about the questionnaire, **please feel free to contact Joe Williams on joseph.williams.10@ucl.ac.uk**

### 01 - About Yourself

This section about you and your background. Please fill try to fill in all the boxes.

| | | |
|---|---|---|
| What gender are you? | S1Q1 | Male O Female O |
| What school year are you in? | S1Q2 | year 7 O year 8 O year 9 O year 10 O year 11 O |
| When did you first start in this school? | S1Q3 | [ ] Month [ ] Year |

### 02 - About Your School

This section is about how you feel about the school. Please read the each statement and tick the box that corresponds to how you feel about the statement, from **Strongly Disagree** to **Neutral** to **Strongly Agree**. If you are not sure or feel the question does not apply to you, please leave the question blank.

| | | Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree |
|---|---|---|---|---|---|---|
| Teachers are available when I need to talk to them. | S2Q1 | O | O | O | O | O |
| It is easy to talk to the teachers. | S2Q2 | O | O | O | O | O |
| Teachers understand my problems. | S2Q3 | O | O | O | O | O |
| My schoolwork is exciting. | S2Q4 | O | O | O | O | O |
| This school makes students enthusiastic about learning. | S2Q5 | O | O | O | O | O |
| If this school had an extra period during the day, I would take an additional class. | S2Q6 | O | O | O | O | O |
| Students are frequently rewarded or praised by the faculty and staff for following the rules. | S2Q7 | O | O | O | O | O |
| I believe that teachers expect students to learn. | S2Q8 | O | O | O | O | O |
| I try hard in classes. | S2Q9 | O | O | O | O | O |
| I feel that I can do well in my school work. | S2Q10 | O | O | O | O | O |
| Problems in this school are solved by the students and the staff. | S2Q11 | O | O | O | O | O |
| School rules are enforced consistently and fairly. | S2Q12 | O | O | O | O | O |
| I am happy, in general, with the other students who go to my school. | S2Q13 | O | O | O | O | O |
| At my school, the same person always gets chosen every time to take part in after-school or special activities. | S2Q14 | O | O | O | O | O |

**Page 1 of 3**

## 02 - About Your School (continued)

| | Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree |
|---|---|---|---|---|---|
| I am happy with the amount of tests I have. S2Q15 | O | O | O | O | O |
| Overall I think the school is very good. S2Q16 | O | O | O | O | O |

## 03 - About Your School Building

This section is about how you feel about the school building. Please read the each statement and tick the box that corresponds to how you feel about the statement, from **Strongly Disagree** to **Neutral** to **Strongly Agree**. If you are not sure or feel the question does not apply to you, please leave the question blank. Please give an average for the spaces that you use.

| | Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree |
|---|---|---|---|---|---|
| The appearance of the inside of the building is pleasant. S3aQ1 | O | O | O | O | O |
| The inside of the building is beautiful. S3aQ2 | O | O | O | O | O |
| The inside of the building is colourful. S3aQ3 | O | O | O | O | O |
| The building is very personalised. S3aQ4 | O | O | O | O | O |
| Overall, the inside of the building looks good. S3aQ5 | O | O | O | O | O |
| The appearance of the outside of the building is pleasant. S3aQ6 | O | O | O | O | O |
| The outside of the building is beautiful. S3aQ7 | O | O | O | O | O |
| The outside of the building is colourful. S3aQ8 | O | O | O | O | O |
| Overall, the outside of the building looks good. S3aQ9 | O | O | O | O | O |
| It is very easy to find my way around the school. S3aQ10 | O | O | O | O | O |
| During breaks and between lessons, I find it easy to move around the building. S3aQ11 | O | O | O | O | O |
| I feel safe throughout the school grounds. S3aQ12 | O | O | O | O | O |
| My school is neat and clean. S3aQ13 | O | O | O | O | O |
| My school buildings are generally pleasant and well maintained. S3aQ14 | O | O | O | O | O |

This next set of questions are about the school environment please read each question carefully and note that the scale for each question may be different. For some questions the central point is **neutral**, but for others it is **perfect**. Give an average for the spaces that you use. **If this is your first year in the school, then only answer the questions for winter.**

| | | | | | | |
|---|---|---|---|---|---|---|
| In *winter*, how is the temperature: S3bQ15 | Too cold O | O | Perfect O | O | O Too hot |
| In *winter*, how is the air in the rooms: S3bQ16 | Stuffy O | O | Neutral O | O | O Fresh |
| In *winter*, how is the air in the rooms: S3bQ17 | Smelly O | O | Neutral O | O | O Odourless |
| In *summer*, how is the temperature: S3bQ18 | Too cold O | O | Perfect O | O | O Too hot |
| In *summer*, how is the air in the rooms: S3bQ19 | Stuffy O | O | Neutral O | O | O Fresh |
| In summer, how is the air in the rooms: S3bQ20 | Smelly O | O | Neutral O | O | O Odourless |

**Page 2 of 3**

## 03 - About Your School Building (continued)

| | | Too little | | Perfect | | Too much |
|---|---|---|---|---|---|---|
| Is there enough daylight in the classrooms: | S3bQ21 | O | O | O | O | O |
| Is there enough daylight in the the rest of the building: | S3bQ22 | O | O | O | O | O |

This next set of questions are about the noise levels within the school building.

| | | Frequently | Occasionally | Rarely | Never |
|---|---|---|---|---|---|
| How often are you distracted by noises from other internal areas? | S3cQ23 | O | O | O | O |
| How often are you distracted by noises from the outside? | S3cQ24 | O | O | O | O |
| How often are you distracted by noises from within the rooms (e.g.: from printers)? | S3cQ25 | O | O | O | O |

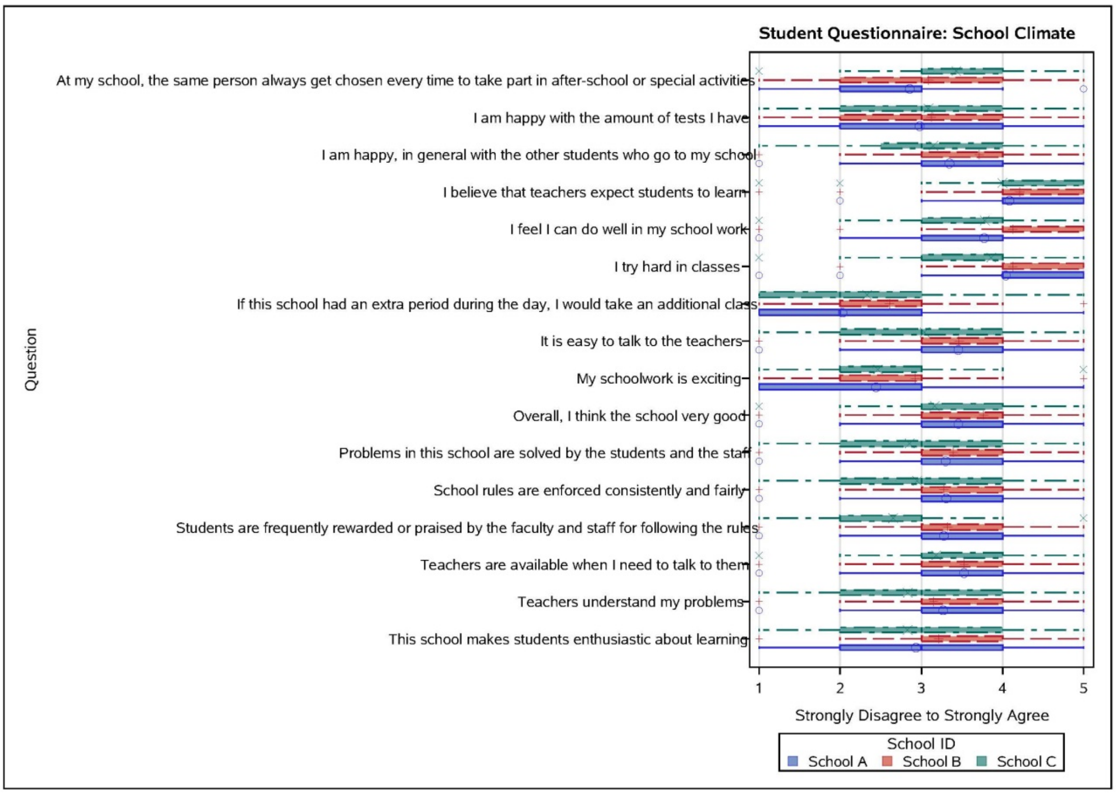
| Overall, how would you rate the building: | | Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree |
|---|---|---|---|---|---|---|
| Overall, the conditions in *winter* are very good. | S3dQ26 | O | O | O | O | O |
| Overall, the conditions in *summer* are very good. | S3dQ27 | O | O | O | O | O |
| Overall, the building is very good. | S3dQ28 | O | O | O | O | O |
| Overall, thinking about the school and the building, this school is very good. | S3dQ29 | O | O | O | O | O |

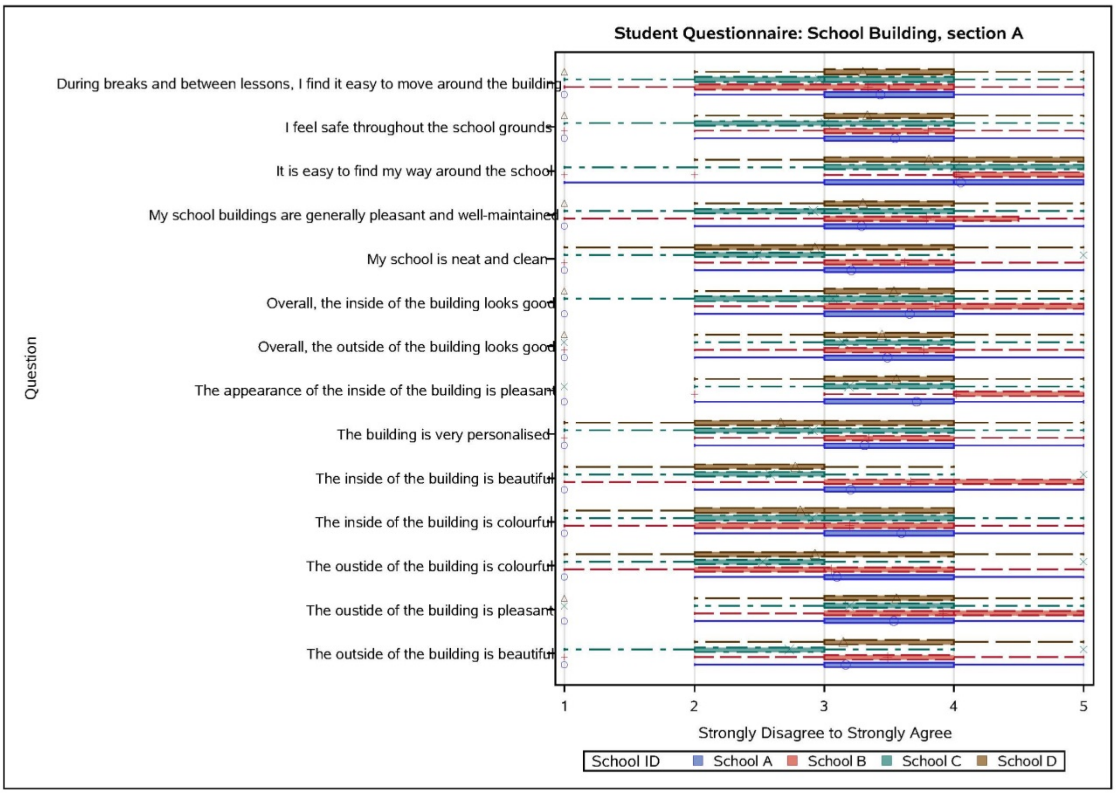
Please use the space below to tell us about any specific aspects of the school building or school that you think are important, and/or clarify some of the choices you have made in this questionnaire. If you run out of space, feel free to use an additional piece of paper.

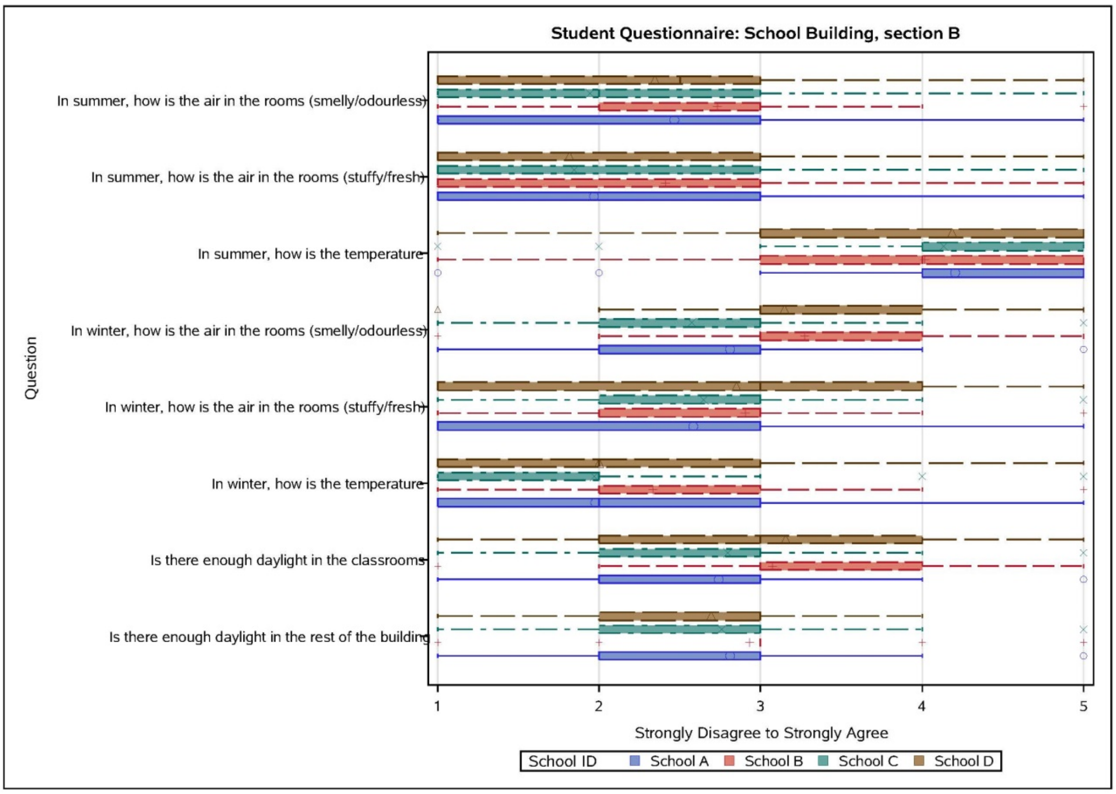
Thank you again for taking the time to complete this questionnaire.

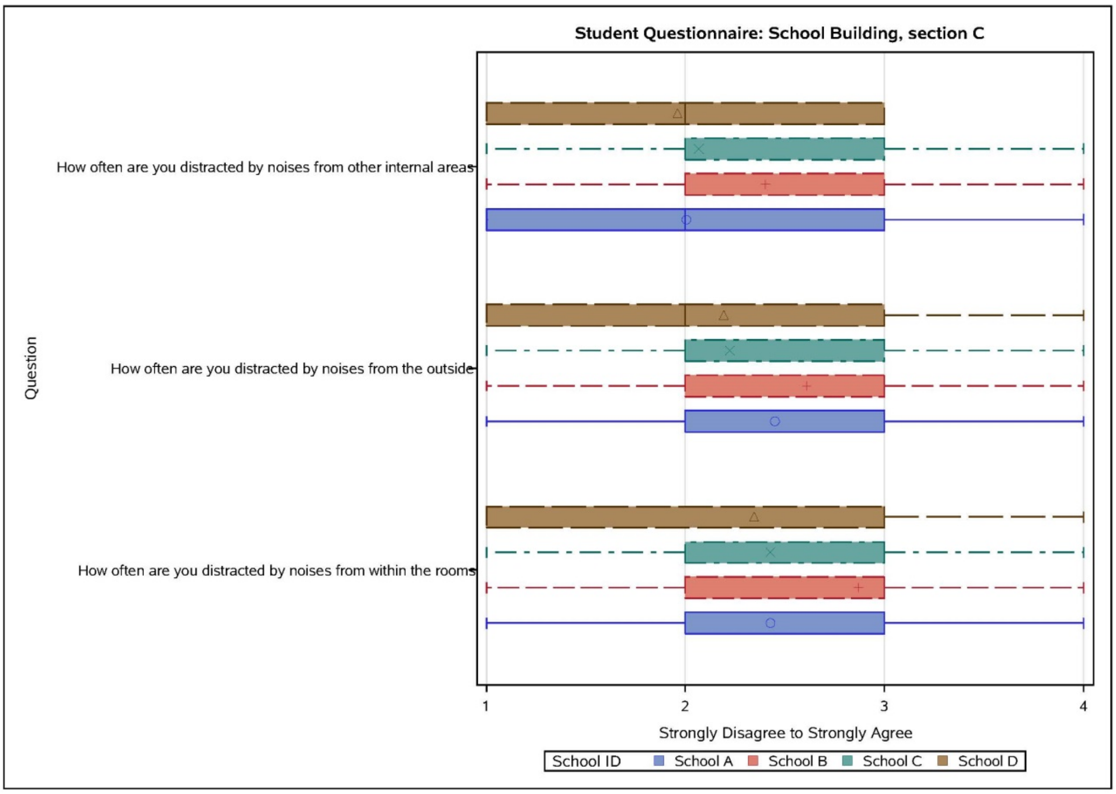
Produced by Joe Williams at University College London, Bartlett School of Graduate Studies, 2013 **Page 3 of 3**

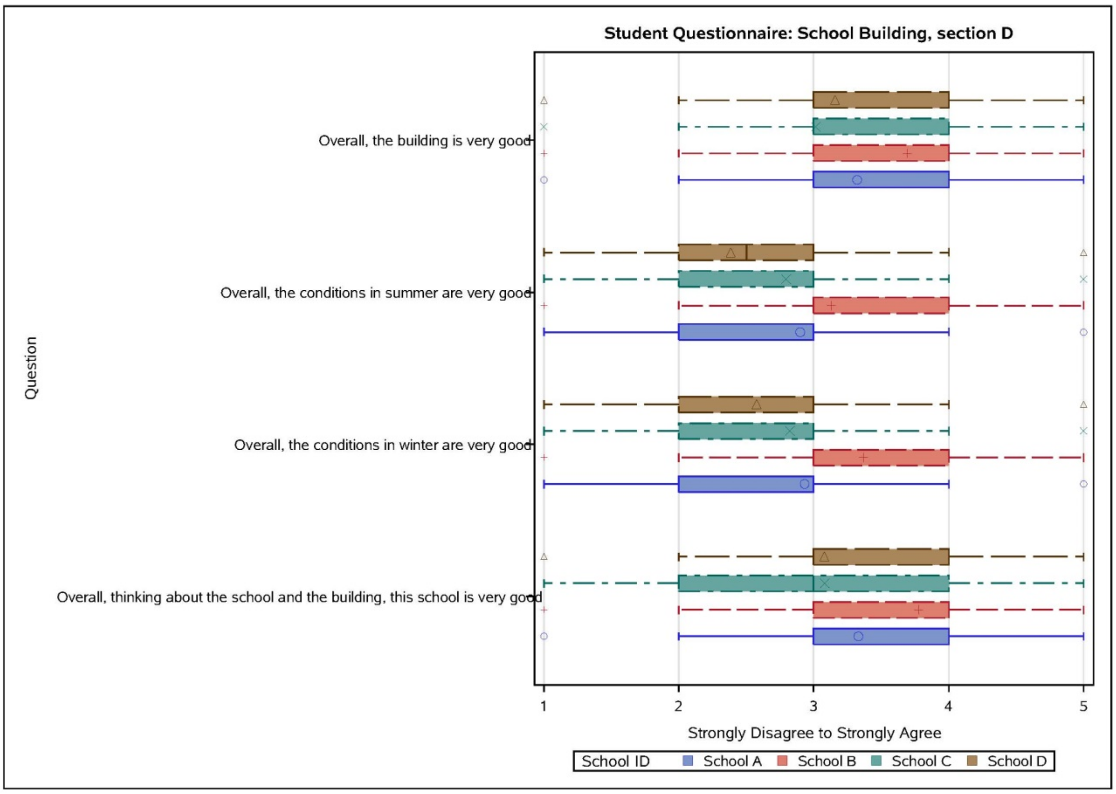
# Appendix D. Questionnaire Results




Student Questionnaire: School Building, section B
In summer, how is the air in the rooms (smelly/odourless)
In summer, how is the air in the rooms (stuffy/fresh)
In summer, how is the temperature
In winter, how is the air in the rooms (smelly/odourless)
In winter, how is the air in the rooms (stuffy/fresh)
In winter, how is the temperature
Is there enough daylight in the classrooms
Is there enough daylight in the rest of the building
Question
1
2
3
4
5
Strongly Disagree to Strongly Agree
School ID
School A
School B
School C
School D


Student Questionnaire: School Building, section C
How often are you distracted by noises from other internal areas
How often are you distracted by noises from the outside
How often are you distracted by noises from within the rooms
Question
1
2
3
4
Strongly Disagree to Strongly Agree
School ID
School A
School B
School C
School D


Student Questionnaire: School Building, section D
Question
Overall, the building is very good
Overall, the conditions in summer are very good
Overall, the conditions in winter are very good
Overall, thinking about the school and the building, this school is very good
1
2
3
4
5
Strongly Disagree to Strongly Agree
School ID
School A
School B
School C
School D

# Appendix E. Questionnaire Factor Analysis Coefficients

**Factor 1 - The appearance and feel of the school (38.6%)**

| Question number | Question wording | Correlation coefficient |
|---|---|---|
| S3aQ5 | *Overall, the inside of the building looks good* | 0.910 |
| S3aQ7 | *The outside of the building is beautiful* | 0.843 |
| S3aQ8 | *The outside of the building is colourful* | 0.833 |
| S3aQ3 | *The inside of the building is colourful* | 0.801 |
| S3aQ2 | *The inside of the building is beautiful* | 0.798 |
| S3aQ6 | *The outside of the building is pleasant* | 0.798 |
| S3aQ9 | *Overall, the outside of the building looks good* | 0.796 |
| S3aQ1 | *The appearance of the inside of the building is pleasant* | 0.738 |
| S3aQ4 | *The building is very personalised* | 0.732 |
| S3aQ13 | *My school is neat and clean* | 0.664 |
| S3aQ14 | *My school buildings are generally pleasant and well-maintained* | 0.604 |
| S3dQ28 | *Overall, the building is very good* | 0.599 |
| S3dQ29 | *Overall, thinking about the school and the building, this school is very good* | 0.599 |
| S2Q16 | *Overall, I think the school very good* | 0.461 |
| S3aQ12 | *I feel safe throughout the school grounds* | 0.435 |
| S3dQ26 | *Overall, the conditions in winter are very good* | 0.362 |
| S3bQ17 | *In winter, how is the air in the rooms (smelly/odourless)* | 0.328 |
| S3dQ27 | *Overall, the conditions in summer are very good* | 0.318 |
| S3aQ11 | *During breaks and between lessons, I find it easy to move around the building* | 0.296 |
| S2Q7 | *Students are frequently rewarded or praised by the faculty and staff for following the rules* | 0.284 |

**Factor 2 - School climate and winter temperature (29.8%)**

| Question number | Question wording | Correlation coefficient |
|---|---|---|
| S2Q2 | *It is easy to talk to the teachers* | 0.753 |
| S2Q10 | *I feel I can do well in my school work* | 0.705 |
| S2Q9 | *I try hard in classes* | 0.704 |
| S2Q3 | *Teachers understand my problems* | 0.704 |
| S2Q1 | *Teachers are available when I need to talk to them* | 0.644 |
| S2Q8 | *I believe that teachers expect students to learn* | 0.607 |
| S2Q11 | *Problems in this school are solved by the students and the staff* | 0.574 |
| S2Q4 | *My schoolwork is exciting* | 0.538 |
| S2Q5 | *This school makes students enthusiastic about learning* | 0.476 |
| S2Q12 | *School rules are enforced consistently and fairly* | 0.464 |
| S2Q15 | *I am happy with the amount of tests I have* | 0.437 |
| S2Q13 | *I am happy, in general with the other students who go to my school* | 0.430 |

**Factor 2 - School climate and winter temperature (29.8%)**

| Question number | Question wording | Correlation coefficient |
|---|---|---|
| S2Q6 | *If this school had an extra period during the day, I would take an additional class* | 0.392 |
| S2Q16 | *Overall, I think the school very good* | 0.336 |
| S2Q7 | *Students are frequently rewarded or praised by the faculty and staff for following the rules* | 0.315 |
| S3bQ15 | *In winter, how is the temperature* | 0.308 |
| S3aQ10 | *It is easy to find my way around the school* | 0.306 |
| S3dQ26 | *Overall, the conditions in winter are very good* | 0.271 |

**Factor 3 - Student interaction (14.7%)**

| Question number | Question wording | Correlation coefficient |
|---|---|---|
| S3cQ24 | *How often are you distracted by noises from the outside* | 0.785 |
| S3cQ25 | *How often are you distracted by noises from within the rooms* | 0.709 |
| S3cQ23 | *How often are you distracted by noises from other internal areas* | 0.622 |
| S2Q13 | *I am happy, in general with the other students who go to my school* | -0.272 |
| S2Q14 | *At my school, the same person always get chosen every time to take part in after-school or special activities* | -0.277 |
| S3aQ11 | *During breaks and between lessons, I find it easy to move around the building* | -0.331 |
| S3aQ12 | *I feel safe throughout the school grounds* | -0.390 |

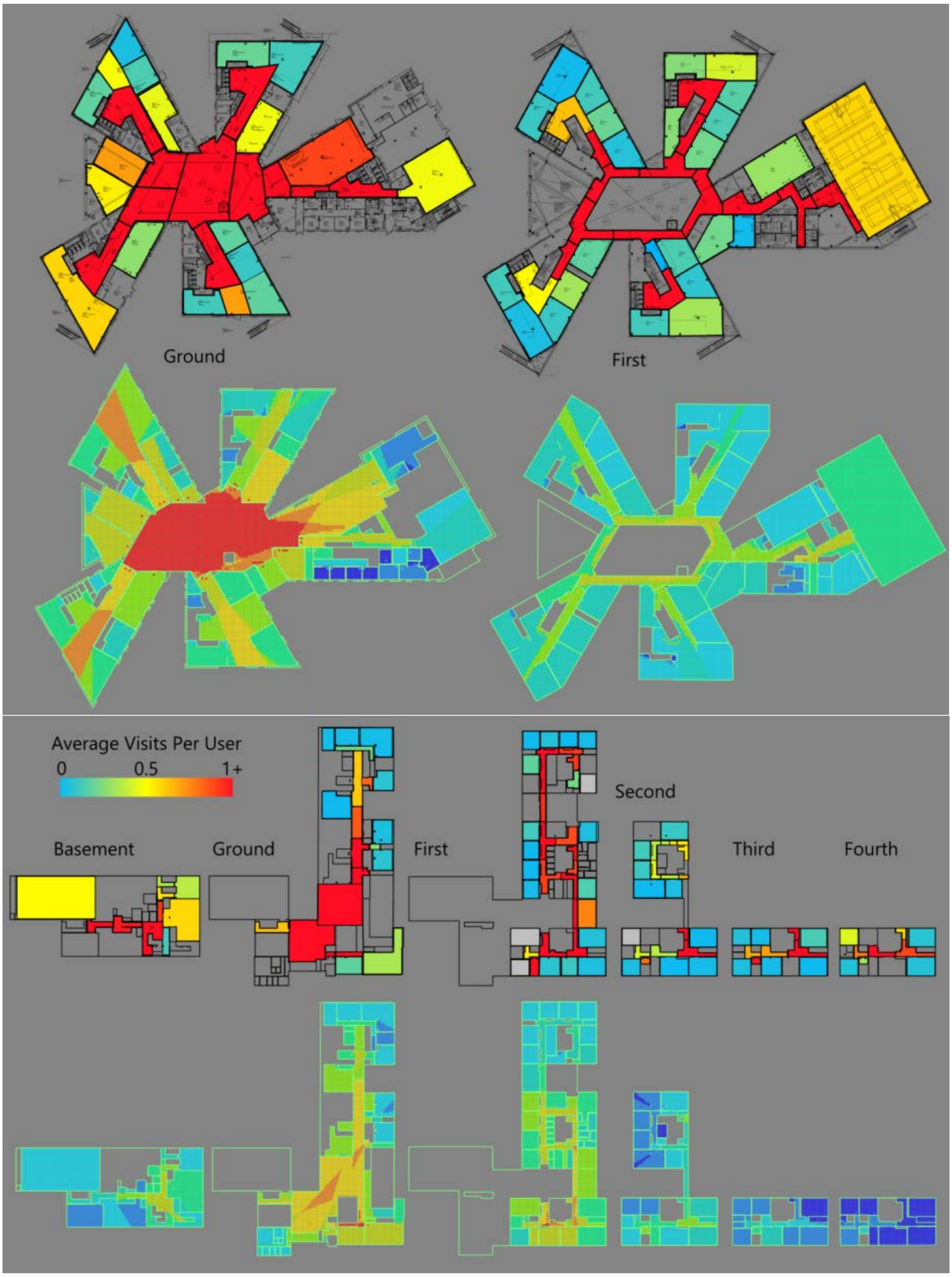
**Factor 4 - Summer comfort, way-finding and extra time within the school (10.0%)**

| Question number | Question wording | Correlation coefficient |
|---|---|---|
| S3bQ19 | *In summer, how is the air in the rooms (stuffy/fresh)* | 0.625 |
| S3bQ20 | *In summer, how is the air in the rooms (smelly/odourless)* | 0.576 |
| S3dQ27 | *Overall, the conditions in summer are very good* | 0.332 |
| S2Q6 | *If this school had an extra period during the day, I would take an additional class* | 0.306 |
| S3aQ10 | *It is easy to find my way around the school* | -0.358 |
| S3bQ18 | *In summer, how is the temperature* | -0.674 |

**Factor 5 - Daylighting (6.9%)**

| Question number | Question wording | Correlation coefficient |
|---|---|---|
| S3bQ21 | *Is there enough daylight in the classrooms* | 0.804 |
| S3bQ22 | *Is there enough daylight in the rest of the building* | 0.780 |

# Appendix F. ISAT Navigation and VGA Integration Maps




ISAT navigation compared to VGA integration. Top: School A (with ISAT results on the top row), and bottom school B (with ISAT results the top row). Note the ISAT scale is typical visits per person, with red representing 1 or more. The VGA scale uses the same colour scale.

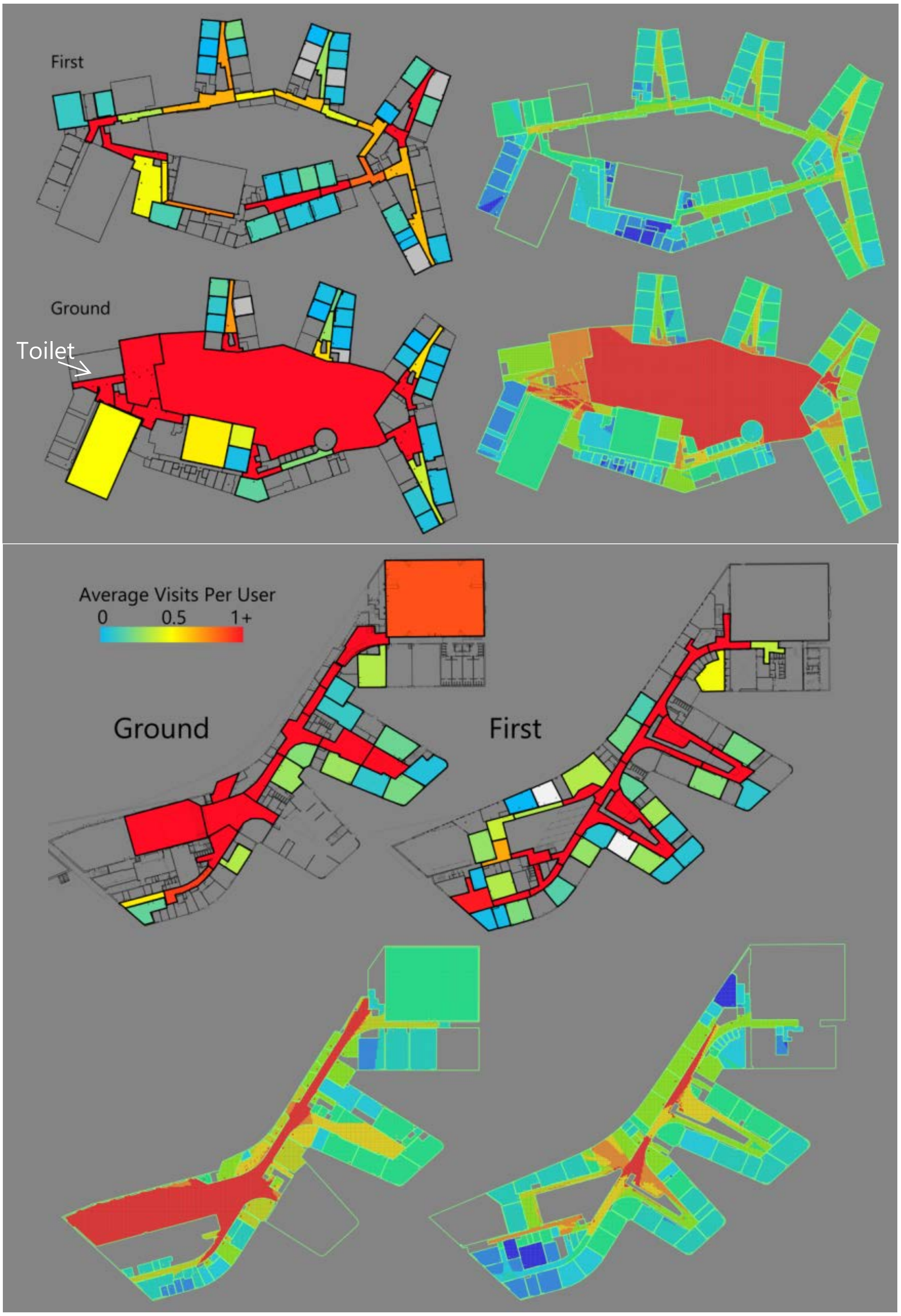



Figure 14.1 – ISAT navigation compared to VGA integration. Top: School C (with ISAT results on the left), and bottom school D (with ISAT results the top two). Note the ISAT scale is typical visits per person, with red representing 1 or more. The VGA scale uses the same colour scale.

# Appendix G. Results of Multilevel Modelling of Measured Environment and Questionnaire

Note, figures in *italics* are significant to $p<0.05$, all other figures are significant at $p<0.01$. * indicates no significant results, and ~ indicates not tested.

| Environmental parameter | Question | | | | | |
|---|---|---|---|---|---|---|
| | S3bQ15 | | S3bQ16 | | S3bQ17 | |
| | In winter, how is the temperature | | In winter, how is the air in the rooms (stuffy/fresh) | | In winter, how is the air in the rooms (smelly/odourless) | |
| | β | SE | β | SE | β | SE |
| CO2 internal (average ppm) | * | * | * | * | * | * |
| CO2 external(average ppm) | 0.033 | 0.004 | 0.043 | 0.003 | 0.029 | 0.007 |
| CO2 difference (average ppm) | * | * | * | * | * | * |
| NO2 internal (μg/m$^3$) | 0.040 | 0.004 | 0.054 | 0.003 | * | * |
| NO2 external (μg/m$^3$) | 0.026 | 0.003 | 0.036 | 0.002 | *0.014* | *0.008* |
| NO2 difference (μg/m$^3$) | -0.076 | 0.009 | -0.106 | 0.006 | -0.146 | 0.005 |
| PM1 Particulates (μg/m$^3$) | -0.046 | 0.007 | -0.066 | 0.005 | -0.098 | 0.004 |
| PM2.5 Particulates (μg/m$^3$) | -0.045 | 0.007 | -0.064 | 0.005 | -0.095 | 0.003 |
| PM10 Particulates (μg/m$^3$) | -0.037 | 0.006 | -0.053 | 0.004 | -0.079 | 0.003 |
| TVOC Internal (ppm) | * | * | * | * | -3.599 | 0.885 |
| TVOC External (ppm) | 11.495 | 1.305 | 15.551 | 0.923 | 19.180 | 1.615 |
| TVOC Difference (ppm) | * | * | *-1.010* | *0.538* | -4.491 | 0.288 |
| Temperature Internal (°C) | * | * | * | * | 0.602 | 0.056 |
| Temperature External (°C) | -0.195 | 0.026 | -0.255 | 0.021 | -0.207 | 0.044 |
| Temperature Difference (°C) | 0.191 | 0.023 | 0.263 | 0.016 | 0.372 | 0.014 |

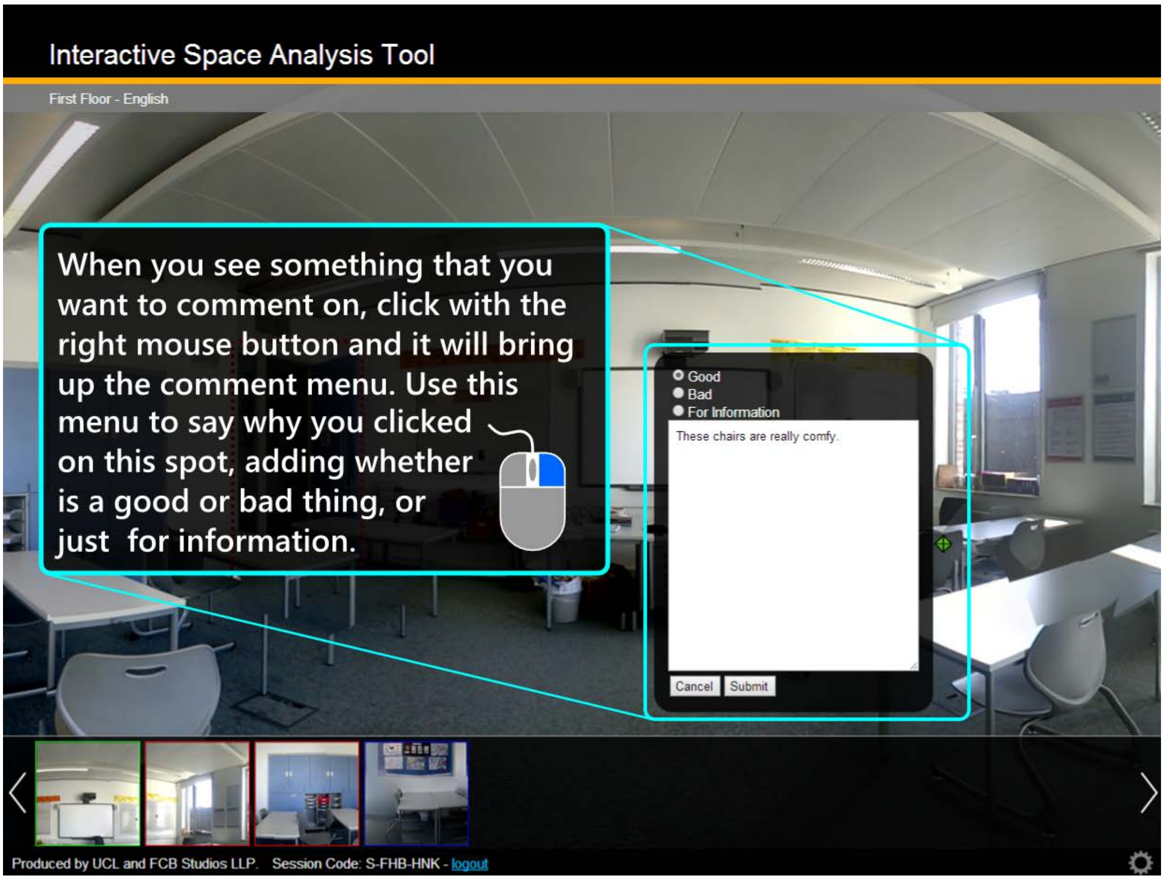
| Environmental parameter | Question | | | | | |
|---|---|---|---|---|---|---|
| | **s3bq18** In summer, how is the temperature | | **S3bQ19** In summer, how is the air in the rooms (stuffy/fresh) | | **S3bQ20** In summer, how is the air in the rooms (smelly/odourless) | |
| | **β** | **SE** | **β** | **SE** | **β** | **SE** |
| **CO2 internal (average ppm)** | * | * | * | * | * | * |
| **CO2 external(average ppm)** | 0.018 | 0.001 | 0.017 | 0.007 | * | * |
| **CO2 difference (average ppm)** | * | * | * | * | * | * |
| **NO2 internal (μg/m$^3$)** | 0.027 | 0.001 | 0.027 | 0.006 | * | * |
| **NO2 external (μg/m$^3$)** | 0.019 | 0.001 | 0.019 | 0.004 | * | * |
| **NO2 difference (μg/m$^3$)** | -0.065 | 0.002 | -0.062 | 0.012 | *-0.108* | *0.058* |
| **PM1 Particulates (mg/m$^3$)** | -0.040 | 0.001 | -0.041 | 0.008 | -0.061 | 0.009 |
| **PM2.5 Particulates (mg/m$^3$)** | -0.039 | 0.001 | -0.040 | 0.008 | -0.059 | 0.009 |
| **PM10 Particulates (mg/m$^3$)** | -0.033 | 0.001 | -0.034 | 0.006 | -0.052 | 0.007 |
| **TVOC Internal (ppm)** | -1.756 | 0.093 | -1.812 | 0.52 | -4.631 | 0.424 |
| **TVOC External (ppm)** | 13.410 | 0.280 | 8.749 | 1.745 | 10.171 | 4.044 |
| **TVOC Difference (ppm)** | -1.939 | 0.080 | -1.898 | 0.449 | -4.236 | 0.362 |
| **Temperature Internal (°C)** | 0.251 | 0.012 | 0.235 | 0.075 | 0.599 | 0.054 |
| **Temperature External (°C)** | -0.086 | 0.006 | *-0.105* | *0.047* | * | * |
| **Temperature Difference (°C)** | 0.148 | 0.005 | 0.158 | 0.03 | 0.247 | 0.064 |

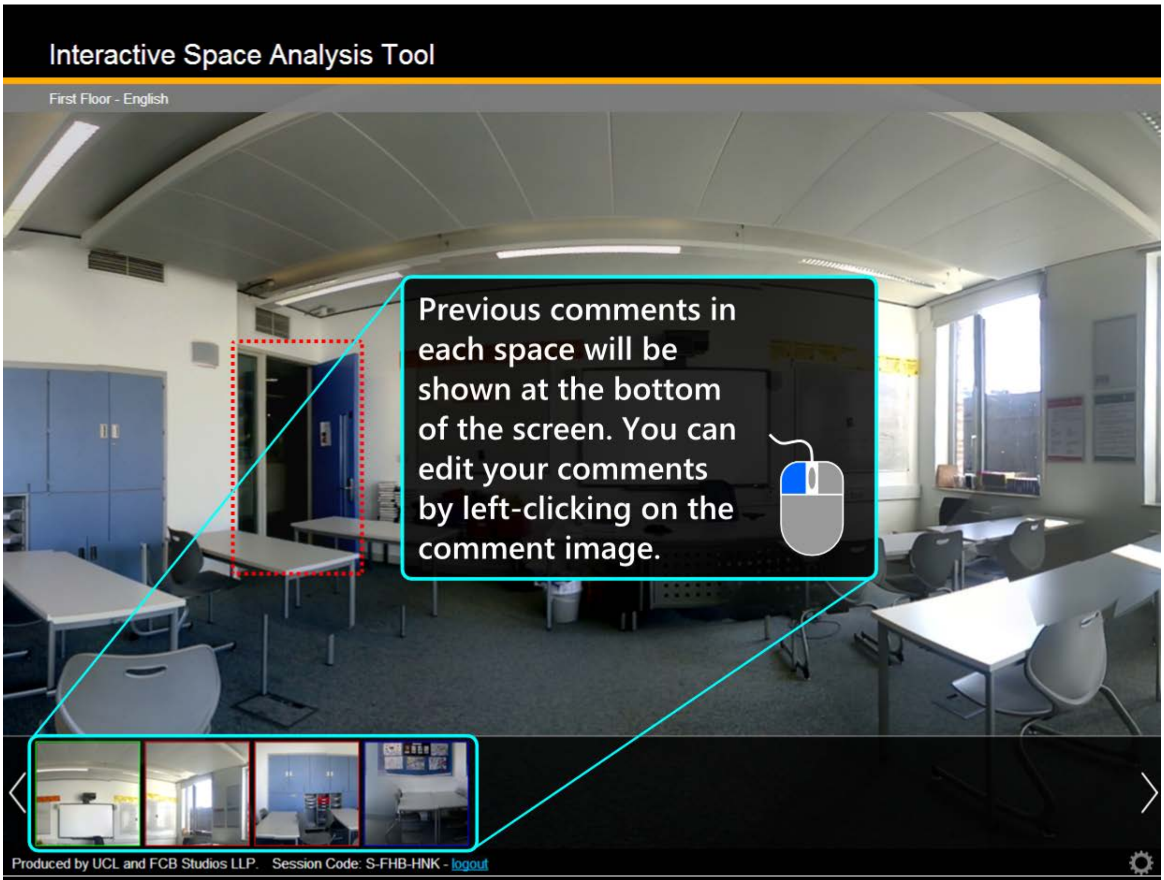
| Environmental parameter | Question | | | |
|---|---|---|---|---|
| | S3aQ10 It is easy to find my way around the school | | S3aQ11 During breaks and between lessons, I find it easy to move around the building | |
| | β | SE | β | SE |
| **Pupil Density ($m^2$/pupils)** | 0.294 | 0.006 | 0.221 | 0.018 |
| **VGA Integration (HH)** | -0.157 | 0.03 | *0.158* | *0.076* |
| **Mean depth** | 0.112 | 0.013 | *-0.072* | *0.043* |
| **Intelligibility** | -1.363 | 0.032 | * | * |

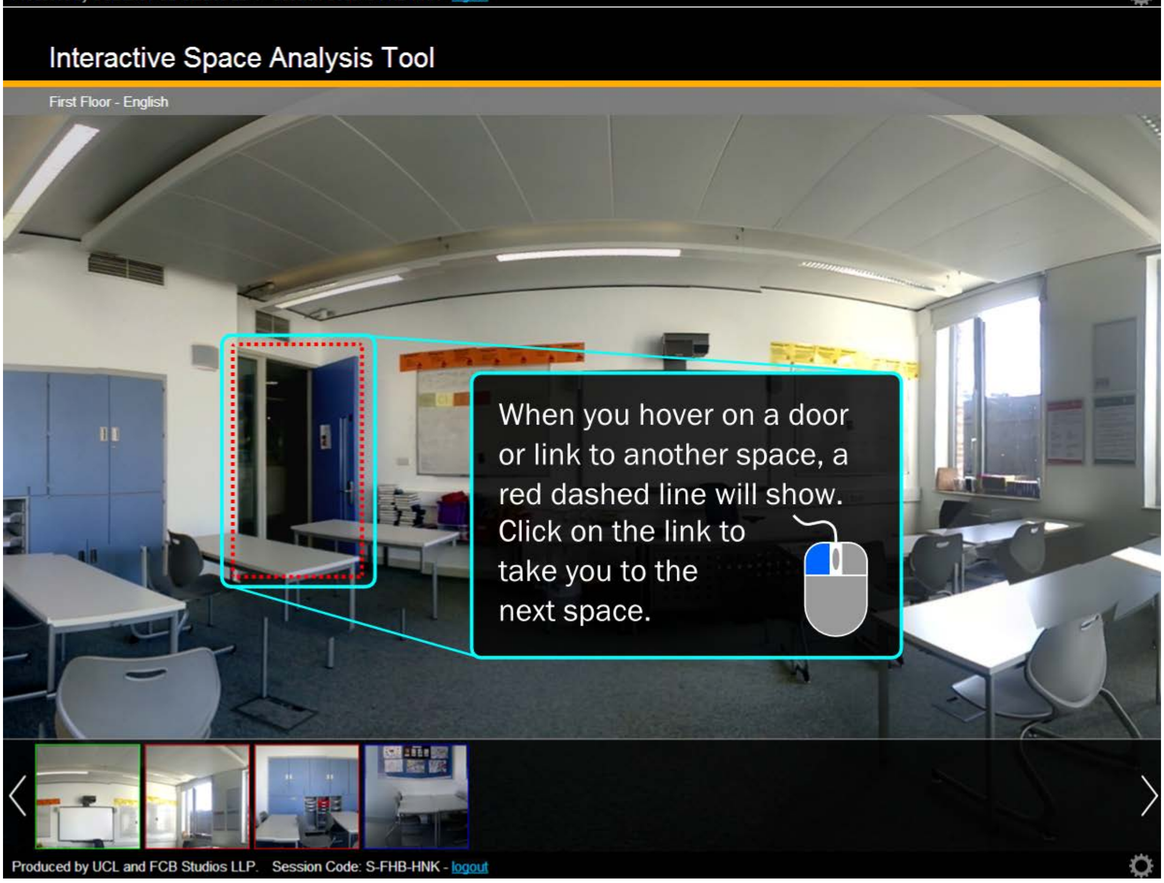
| Environmental parameter | Question | |
|---|---|---|
| | S3bQ21 Is there enough daylight in the classrooms | |
| | β | SE |
| **Daylight Factor (%)** | -28.49 | 4.984 |

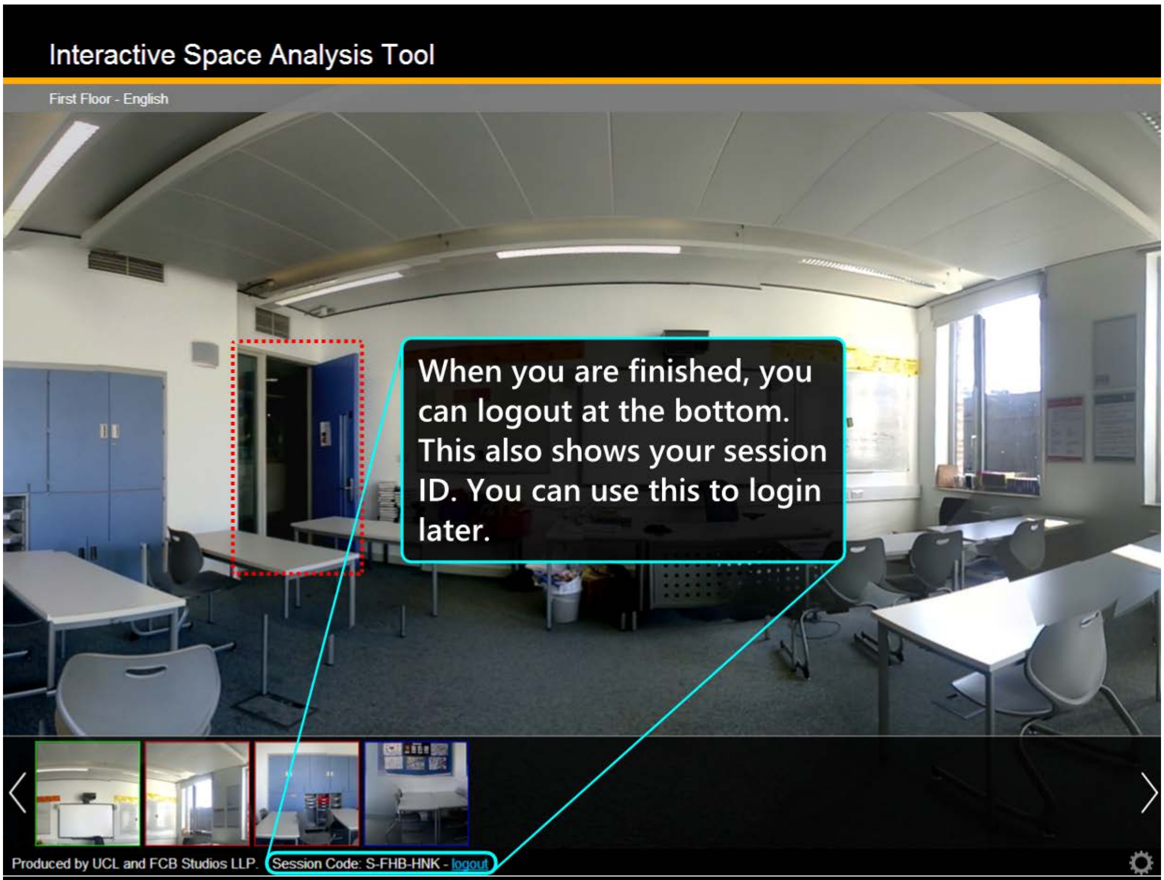
| Environmental parameter | Question | |
|---|---|---|
| | S3cQ24 How often are you distracted by noises from the outside | |
| | β | SE |
| **Ambient Noise $L_{Aeq, 5 min}$ Internal (dB)** | 0.120 | 0.007 |
| **Ambient Noise $L_{Aeq, 5 min}$ External (dB)** | * | * |
| **Reverberation Time RT60 (seconds)** | -11.603 | 0.995 |

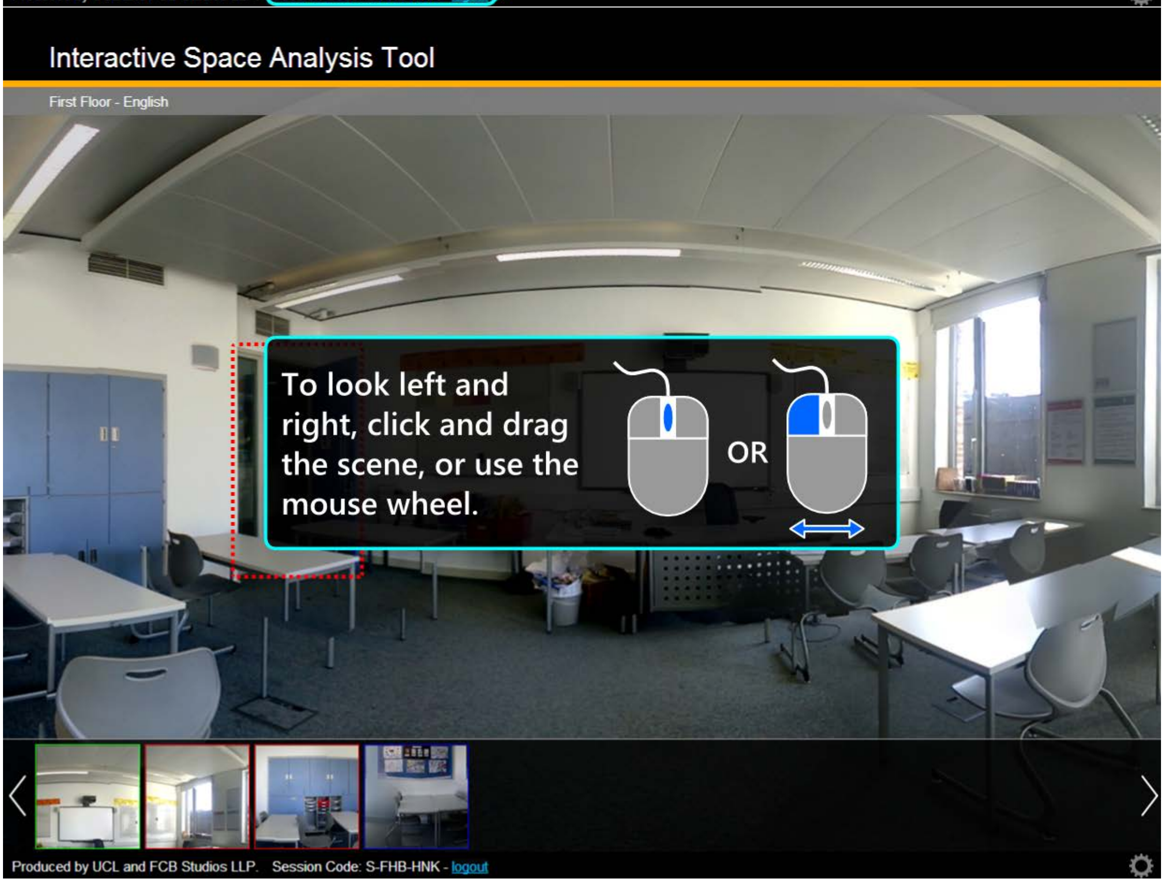
# Appendix H. ISAT Instructions




Interactive Space Analysis Tool
First Floor - English
Previous comments in each space will be shown at the bottom of the screen. You can edit your comments by left-clicking on the comment image.
Produced by UCL and FCB Studios LLP. Session Code: S-FHB-HNK - logout


Interactive Space Analysis Tool
First Floor - English
When you hover on a door or link to another space, a red dashed line will show. Click on the link to take you to the next space.
Produced by UCL and FCB Studios LLP. Session Code: S-FHB-HNK - logout


Interactive Space Analysis Tool
First Floor - English
When you are finished, you can logout at the bottom. This also shows your session ID. You can use this to login later.
Produced by UCL and FCB Studios LLP.
Session Code: S-FHB-HNK - logout


Interactive Space Analysis Tool
First Floor - English
To look left and right, click and drag the scene, or use the mouse wheel.
OR
Produced by UCL and FCB Studios LLP.
Session Code: S-FHB-HNK - logout

# Appendix I. Results from Multilevel Modelling of ISAT and Environmental Measurements

Note, figures in *italics* are significant to p<0.05, all other figures are significant at p<0.01. * indicates no significant results, and ~ indicates not tested.

| Environmental parameter | ISAT Property | | | |
|---|---|---|---|---|
| | Acoustics | | | |
| | Positive | | Negative | |
| | β | SE | β | SE |
| **Reverberation Time RT60 (seconds)** | * | * | * | * |
| **Ambient Noise $L_{Aeq, 5\,min}$ Internal (dB)** | * | * | * | * |
| **Ambient Noise $L_{Aeq, 5\,min}$ External (dB)** | * | * | * | * |

| Environmental parameter | ISAT Property | | | |
|---|---|---|---|---|
| | Daylight | | | |
| | Positive | | Negative | |
| | β | SE | β | SE |
| **Daylight Factor (%)** | 0.376 | 0.153 | * | * |

| Environmental parameter | ISAT Property | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Building Layout | | | | Circulation | | | |
| | Positive | | Negative | | Positive | | Negative | |
| | β | SE | β | SE | β | SE | β | SE |
| **Pupil Density ($m^2$/pupils)** | * | * | * | * | * | * | * | * |
| **VGA Integration (HH)** | -0.039 | 0.014 | *-0.018* | *0.010* | -0.038 | 0.011 | -0.054 | 0.013 |
| **Mean depth** | 0.021 | 0.004 | * | * | 0.020 | 0.003 | 0.026 | 0.006 |
| **Intelligibility** | -0.085 | 0.036 | * | * | -0.083 | 0.030 | *-0.094* | *0.050* |

| **Environmental parameter** | **ISAT Property** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Space Layout** | | | | **Space Size** | | | |
| | **Positive** | | **Negative** | | **Positive** | | **Negative** | |
| | **β** | **SE** | **β** | **SE** | **β** | **SE** | **β** | **SE** |
| **Pupil Density ($m^2$/pupils)** | 0.005 | 0.002 | * | * | * | * | * | * |
| **VGA Integration (HH)** | * | * | * | * | -0.039 | 0.010 | * | * |
| **Mean depth** | * | * | * | * | 0.020 | 0.002 | * | * |
| **Intelligibility** | -0.074 | 0.022 | * | * | -0.075 | 0.034 | * | * |

| **Environmental parameter** | **ISAT Property** | | | |
|---|---|---|---|---|
| | **Visibility** | | | |
| | **Positive** | | **Negative** | |
| | **β** | **SE** | **β** | **SE** |
| **Pupil Density ($m^2$/pupils)** | * | * | *-0.002* | *0.001* |
| **VGA Integration (HH)** | -0.038 | 0.007 | -0.017 | 0.002 |
| **Mean depth** | 0.019 | 0.001 | 0.007 | 0.002 |
| **Intelligibility** | *-0.062* | *0.035* | * | * |

| Environmental parameter | ISAT Property | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Air Quality | | | | Temperature | | | |
| | Positive | | Negative | | Positive | | Negative | |
| | β | SE | β | SE | β | SE | β | SE |
| **$CO_2$ internal (ppm)** | * | * | * | * | * | * | * | * |
| **$CO_2$ External (ppm)** | * | * | * | * | * | * | -0.006 | 0.002 |
| **$CO_2$ difference (ppm)** | * | * | * | * | * | * | * | * |
| **$NO_2$ internal (µg/m$^3$)** | * | * | * | * | * | * | *-0.005* | *0.003* |
| **$NO_2$ external (µg/m$^3$)** | * | * | * | * | * | * | * | * |
| **$NO_2$ difference (µg/m$^3$)** | * | * | * | * | * | * | * | * |
| **PM1 Particulates (µg/m$^3$)** | * | * | *1.600* | *0.928* | * | * | * | * |
| **PM2.5 Particulates (µg/m$^3$)** | * | * | *1.558* | *0.898* | * | * | * | * |
| **PM10 Particulates (µg/m$^3$)** | * | * | *1.220* | *0.713* | * | * | * | * |
| **TVOCs Internal (ppm)** | -0.040 | 0.007 | * | * | * | * | * | * |
| **TVOCs External (ppm)** | 0.091 | 0.044 | * | * | * | * | * | * |
| **TVOC Difference (ppm)** | -0.035 | 0.002 | * | * | * | * | * | * |
| **Temperature Internal (°C)** | 0.005 | 0.001 | * | * | * | * | * | * |
| **Temperature External (°C)** | * | * | 0.008 | 0.003 | *0.004* | *0.002* | 0.037 | 0.009 |
| **Temperature Difference (°C)** | 0.002 | 0.001 | * | * | * | * | * | * |

## Appendix J. Results from Multilevel Modelling of Positive ISAT and Questionnaire Results

Note, figures in *italics* are significant to p<0.05, all other figures are significant at p<0.01. * indicates no significant results, and ~ indicates not tested.

| Questionnaire Question | | Positive ISAT Property | | | | | |
|---|---|---|---|---|---|---|---|
| | | General Feeling | | Control of Lessons | | Lessons | |
| | | β | SE | β | SE | β | SE |
| S2Q16 | Overall, I think the school is very good | 11.998 | 0.321 | 200.951 | 5.942 | 23.539 | 0.66 |
| S3DQ28 | Overall, the building is very good | 19.406 | 0.296 | ~ | ~ | 26.308 | 0.822 |
| S3DQ29 | Overall, thinking about the school and the building, this school is very good | 19.97 | 0.261 | ~ | ~ | 23.406 | 0.598 |

| Questionnaire Question | | Positive ISAT Property | |
|---|---|---|---|
| | | Aesthetics | |
| | | β | SE |
| S3AQ1 | The appearance of the inside of the building is pleasant | 550.774 | 0.882 |
| S3AQ2 | The inside of the building is beautiful | -13.243 | 1.507 |
| S3AQ3 | The inside of the building is colourful | -17.904 | 0.991 |
| S3AQ4 | The building is very personalised | -19.508 | 2.669 |
| S3AQ5 | Overall, the inside of the building looks good | * | * |

| Questionnaire Question | | Positive ISAT Property | | | | | |
|---|---|---|---|---|---|---|---|
| | | Circulation | | Control of Spaces | | Building Layout | |
| | | β | SE | β | SE | β | SE |
| S3AQ10 | It is easy to find my way around the school | 9.130 | 0.333 | 328.069 | 8.421 | -47.448 | 7.034 |
| S3AQ11 | During breaks and between lessons, I find it easy to move around the building | 63.745 | 2.309 | 407.901 | 29.575 | * | * |

| Questionnaire Question | | Positive ISAT Property Visibility | |
|---|---|---|---|
| | | β | SE |
| S3AQ12 | I feel safe throughout the school grounds | * | * |

| Questionnaire Question | | Positive ISAT Property Cleaning | |
|---|---|---|---|
| | | β | SE |
| S3AQ13 | My school is neat and clean | -64.58 | 14.344 |

| Questionnaire Question | | Positive ISAT Property Cleaning | |
|---|---|---|---|
| | | β | SE |
| S3AQ14 | My school buildings are generally pleasant and well-maintained | 136.343 | 9.695 |

| Questionnaire Question | | Positive ISAT Property | | | |
|---|---|---|---|---|---|
| | | Air Quality | | Temperature | |
| | | β | SE | β | SE |
| S3BQ15 | In winter, how is the temperature | 303.758 | 36.667 | -24.981 | 5.871 |
| S3BQ16 | In winter, how is the air in the rooms (stuffy/fresh) | *29.038* | *13.192* | * | * |
| S3BQ17 | In winter, how is the air in the rooms (smelly/odourless) | 205.931 | 20.744 | * | * |
| S3BQ18 | In summer, how is the temperature | 62.358 | 2.285 | 4.528 | 1.253 |
| S3BQ19 | In summer, how is the air in the rooms (stuffy/fresh) | 58.375 | 12.988 | * | * |
| S3BQ20 | In summer, how is the air in the rooms (smelly/odourless) | 124.874 | 10.295 | * | * |

| Questionnaire Question | | Positive ISAT Property<br>Visibility<br>β | SE |
|---|---|---|---|
| S3BQ21 | Is there enough daylight in the classrooms | 255.616 | 11.674 |

| Questionnaire Question | | Positive ISAT Property<br>Visibility<br>β | SE |
|---|---|---|---|
| s3cq23 | How often are you distracted by noises from other internal areas | -37.434 | 4.551 |
| s3cq24 | How often are you distracted by noises from the outside | * | * |
| s3cq25 | How often are you distracted by noises from within the rooms | -8.165 | 3.345 |

## Appendix K. Results from Multilevel Modelling of Negative ISAT and Questionnaire Results

Note, figures in *italics* are significant to p<0.05, all other figures are significant at p<0.01. * indicates no significant results, and ~ indicates not tested.

| Questionnaire Question | | Negative ISAT Property | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | General Feeling | | Control of Lessons | | Lessons | | Student Behaviour | |
| | | β | SE | β | SE | β | SE | β | SE |
| S2Q16 | Overall, I think the school is very good | -79.701 | 6.016 | -67.750 | 2.158 | -112.95 | 3.028 | -27.359 | 0.808 |
| S3AQ12 | I feel safe throughout the school grounds | ~ | ~ | ~ | ~ | ~ | ~ | -39.391 | 0.814 |
| S3DQ28 | Overall, the building is very good | -136.67 | 7.965 | ~ | ~ | -162.82 | 2.904 | ~ | ~ |
| S3DQ29 | Overall, thinking about the school and the building, this school is very good | -118.92 | 5.994 | ~ | ~ | -134.79 | 2.491 | ~ | ~ |

| Questionnaire Question | | Negative ISAT Property | |
|---|---|---|---|
| | | Aesthetics | |
| | | β | SE |
| S3AQ1 | The appearance of the inside of the building is pleasant | *-6.372* | *2.972* |
| S3AQ2 | The inside of the building is beautiful | -7.335 | 1.209 |
| S3AQ3 | The inside of the building is colourful | -10.078 | 0.875 |
| S3AQ4 | The building is very personalised | -5.983 | 0.818 |
| S3AQ5 | Overall, the inside of the building looks good | -3.826 | 0.617 |

| Questionnaire Question | | Negative ISAT Property | | | | | |
|---|---|---|---|---|---|---|---|
| | | Circulation | | Control of Spaces | | Building Layout | |
| | | β | SE | β | SE | β | SE |
| S3AQ10 | It is easy to find my way around the school | 12.138 | 0.300 | -18.166 | 0.370 | -28.422 | 0.441 |
| S3AQ11 | During breaks and between lessons, I find it easy to move around the building | 16.846 | 1.344 | -18.195 | 0.686 | -37.274 | 0.832 |

| Questionnaire Question | | Negative ISAT Property | |
|---|---|---|---|
| | | Visibility | |
| | | β | SE |
| S3AQ12 | I feel safe throughout the school grounds | * | * |

| Questionnaire Question | | Negative ISAT Property | |
|---|---|---|---|
| | | Cleaning | |
| | | β | SE |
| S3aQ13 | My school is neat and clean | -21.200 | 0.530 |

| Questionnaire Question | | Negative ISAT Property | |
|---|---|---|---|
| | | Cleaning | |
| | | β | SE |
| S3aQ14 | My school buildings are generally pleasant and well-maintained | -23.959 | 0.682 |

| Questionnaire Question | | Negative ISAT Property | | | |
|---|---|---|---|---|---|
| | | Air Quality | | Temperature | |
| | | β | SE | β | SE |
| S3bq15 | In winter, how is the temperature | -25.100 | 7.518 | -3.142 | 0.644 |
| S3bQ16 | In winter, how is the air in the rooms (stuffy/fresh) | *-41.632* | *16.050* | * | * |
| S3bQ17 | In winter, how is the air in the rooms (smelly/odourless) | -26.903 | 7.976 | 1.083 | 0.414 |
| S3bQ18 | In summer, how is the temperature | -28.820 | 4.073 | * | * |
| S3bQ19 | In summer, how is the air in the rooms (stuffy/fresh) | * | * | * | * |
| S3bQ20 | In summer, how is the air in the rooms (smelly/odourless) | * | * | * | * |

| Questionnaire Question | | Negative ISAT Property | |
|---|---|---|---|
| | | Visibility | |
| | | β | SE |
| S3bQ21 | Is there enough daylight in the classrooms | *41.502* | *24.683* |

| Questionnaire Question | | Negative ISAT Property | |
|---|---|---|---|
| | | Visibility | |
| | | β | SE |
| S3cQ23 | How often are you distracted by noises from other internal areas | -7.119 | 1.580 |
| S3cQ24 | How often are you distracted by noises from the outside | * | * |
| S3cQ25 | How often are you distracted by noises from within the rooms | -2.000 | 0.731 |

# Appendix L. ISAT Feedback Questionnaire

## Interactive Space Analysis Tool Questionnaire

### Thank you for taking the time to complete this questionnaire and using the online tool.

Using this questionnaire, we hope to find out more about the interactive space analysis tool and your experiences using it.

Please answer all the questions. There is space provided at the end for any comments, for example any thoughts or justification for your responses. All responses will be anonymous, with only overall results shared.

If you have any questions about the questionnaire, please feel free to contact Joe Williams on joseph.williams.10@ucl.ac.uk

### 01 - Before you begin

Please fill in this section before you begin

| | |
|---|---|
| Building Code | B - XXX - XXX |
| Session Code | S - XXX - XXX |
| Date | DD - MM - YY |
| Time | HH : MM |

### 02 - Once you have finished

| | | | | Neutral | | | |
|---|---|---|---|---|---|---|---|
| Was the purpose of the tool clear? | Not at all | O | O | O | O | O | Very Clear |
| Were the instructions at the start clear? | Not at all | O | O | O | O | O | Very Clear |
| Was it easy to make a comment? | Not at all | O | O | O | O | O | Very Easy |
| Was it easy to navigate your building? | Not at all | O | O | O | O | O | Very Easy |
| Did the tool help you think about your building? | Not at all | O | O | O | O | O | Very Much |
| Did you enjoy using the tool? | Not at all | O | O | O | O | O | Very Much |

| | |
|---|---|
| Did you have enough time to mention everything about your building? | Yes O O No |
| Were all the spaces you wanted to visit included in the tool? | Yes O O No |

If there were spaces missing, please write down which spaces were missing in area below:

| Did you have any problems using the tool? | Yes O O No |
|---|---|

If there were problems, please write down what problems you encountered in the space below:

If you have any more **comments**, please use the **back of this page**.

Produced by Joe Williams for University College London, Bartlett School of Graduate Studies, 2014